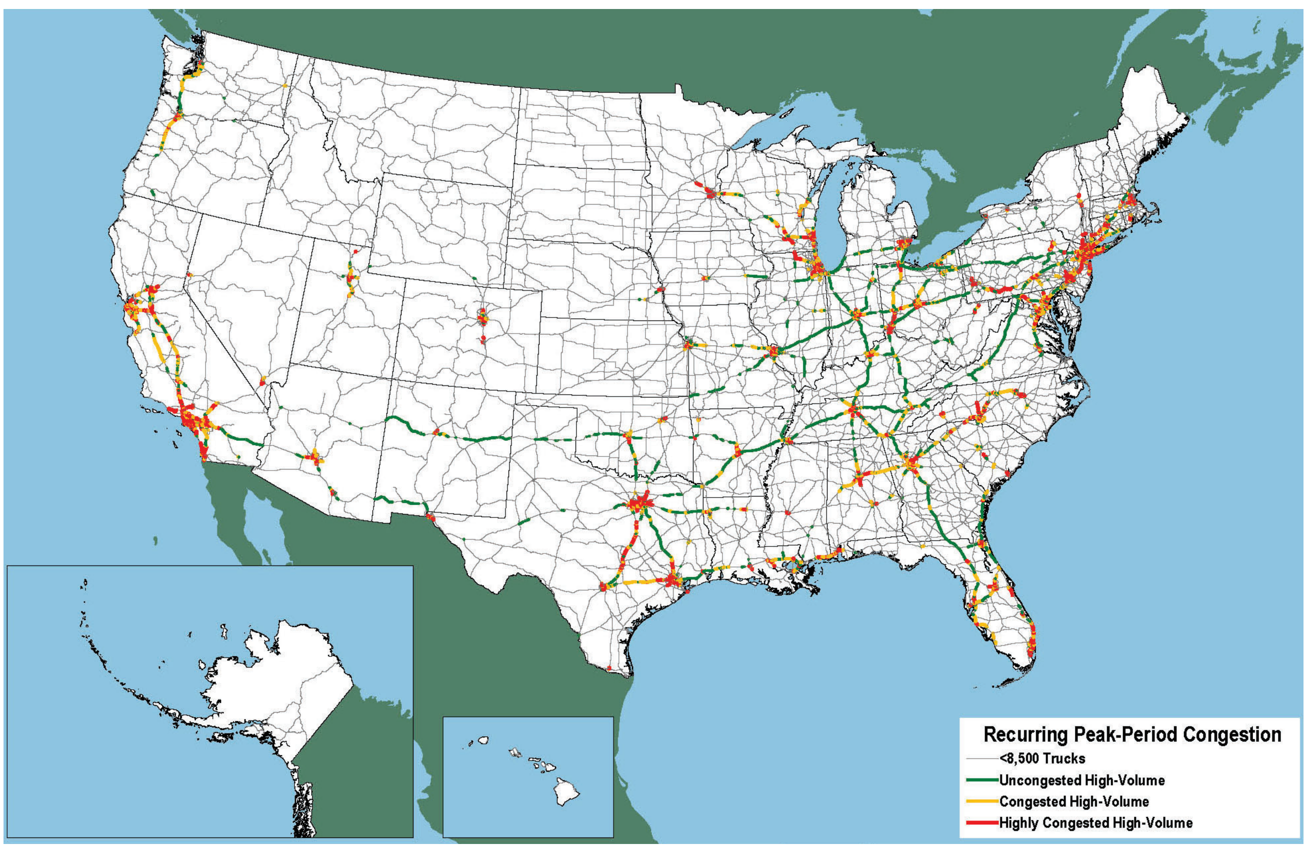
Effect of Congestion and Reliability on Freight Travel

FHWA has created and examined various freight performance measures (FPMs) to analyze the impacts of congestion and determine the operational capacity and efficiency of various Interstate highways and other important freight routes in the United States. Much of the current congestion negatively impacting truck carrier operations occurs on a recurring basis during peak periods of 6 a.m. to 9 a.m. and 4 p.m. to 7 p.m. local time, particularly in and near major metropolitan areas. *Exhibit 5-3* shows a map indicating where this peak period congestion on high-volume truck portions of the National Highway System (NHS) took place

Freight Performance Measurement

The FHWA has been collecting and analyzing data for freight-significant Interstate corridors since 2004. FHWA plans to continue to collect travel time information on 25 interstate corridors and 15 U.S./Canada land-border crossings at least through 2012. Key objectives of the current FPM research program are to expand on the existing data sources; further develop and refine methods for analyzing data; derive national measures of congestion and reliability; analyze freight bottlenecks and intermodal connectors; and develop data products and tools that will assist U.S. DOT, FHWA, and State and local transportation agencies in addressing surface transportation congestion. A web tool for disseminating FPM data on the 25 study corridors, www.freightperformance.org, provides an example of the types of tools that FHWA will develop. The goal is to evolve the research into a credible freight data source that can be used to continuously measure freight performance and inform the development of strategies and tactics for managing and relieving freight congestion.

Exhibit 5-3 Peak-Period Congestion on High-Volume Truck Portions of the National Highway System, 2007



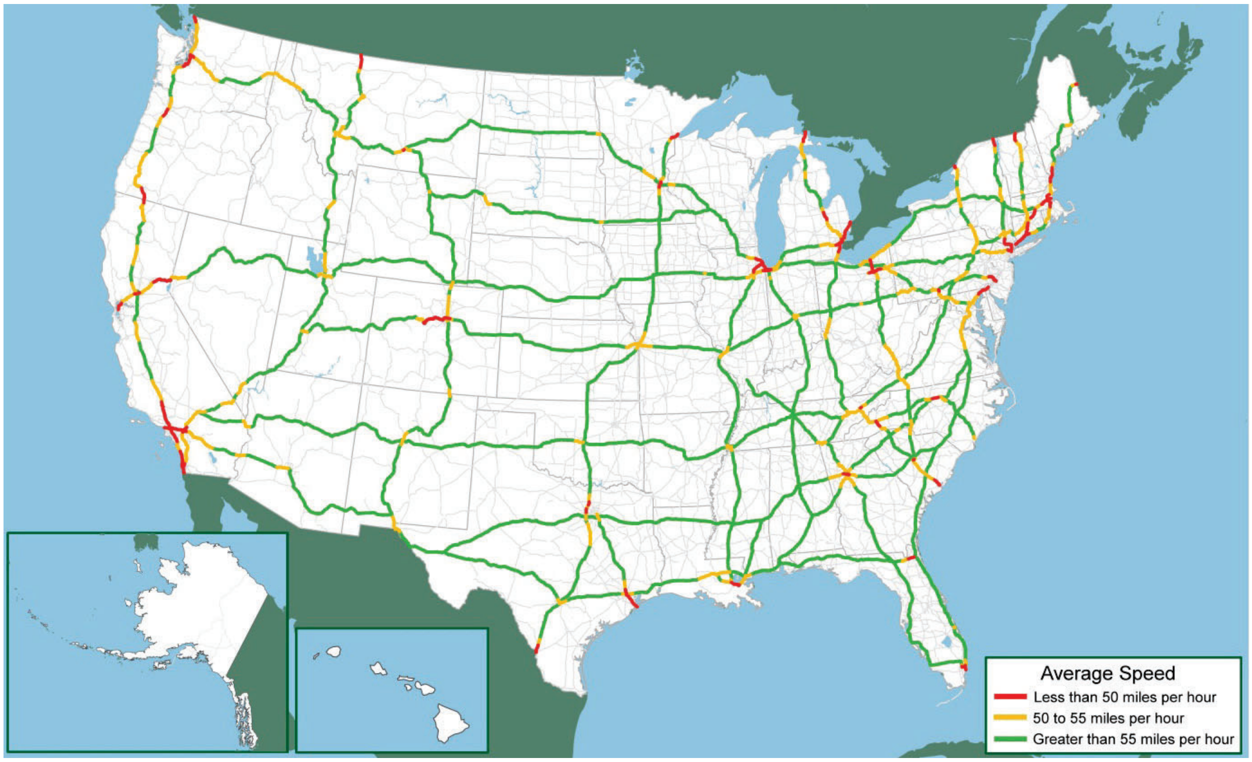
Note: High-volume truck portions of the National Highway System carry more than 8,500 trucks per day, including freight-hauling long-distance trucks, freight-hauling local trucks, and other trucks with six or more tires. Highly congested segments are stop-and-go conditions with volume/service flow ratios greater than 0.95. Congested segments have reduced traffic speeds with volume/service flow ratios between 0.75 and 0.95.

Sources: U.S. Department of Transportation, Federal Highway Administration, Office of Highway Policy Information, Highway Performance Monitoring System, and Office of Freight Management and Operations, Freight Analysis Framework, version 3.2, 2010.

in 2007. Overall, peak period congestion created stop-and-go conditions on 3,700 miles of the NHS and caused traffic to travel below posted speed limits on an additional 4,700 miles of the NHS.

In some locations, freight-hauling trucks are impacted not only during peak periods, but also at other times during the day. In cooperation with private industry, FHWA measures the speed and travel time reliability of more than 500,000 trucks along 25 Interstate corridors on an annual basis. *Exhibit 5-4* shows some of the results of this cooperative initiative, indicating the average truck travel speeds on selected Interstate

Exhibit 5-4 **Average Truck Speeds on Selected Interstate Highways, 2010**



Interstate Route	Average Operating Speed	Average Peak Period Speed*	Average Speed Nonpeak Period	Interstate Route	Average Operating Speed	Average Peak Period Speed*	Average Nonpeak Period Speed
5	53.0	52.1	53.2	70	57.1	56.8	57.2
10	57.8	57.6	58.1	75	57.3	56.7	57.9
15	56.7	56.5	56.8	76	55.4	55.3	55.4
20	59.2	59.0	59.1	77	55.3	54.9	55.3
24	57.5	56.7	57.5	80	58.0	57.8	58.1
25	59.3	59.3	59.2	81	56.8	56.8	56.8
26	54.2	53.8	54.3	84	54.1	52.7	54.5
35	56.9	56.1	57.2	85	57.6	56.7	57.7
40	59.0	58.8	59.1	87	54.5	54.1	54.7
45	55.4	54.3	55.8	90	57.2	57.0	57.3
55	57.8	57.6	57.8	91	53.6	52.8	54.1
65	58.0	57.5	58.1	94	58.4	58.1	58.5
				95	56.5	55.4	57.0

* Both urban and rural areas were combined to determine the speeds shown. This procedure reduces the impact of urban congestion on average speeds. Average speeds are available separated by urban and rural areas on request from the U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations.

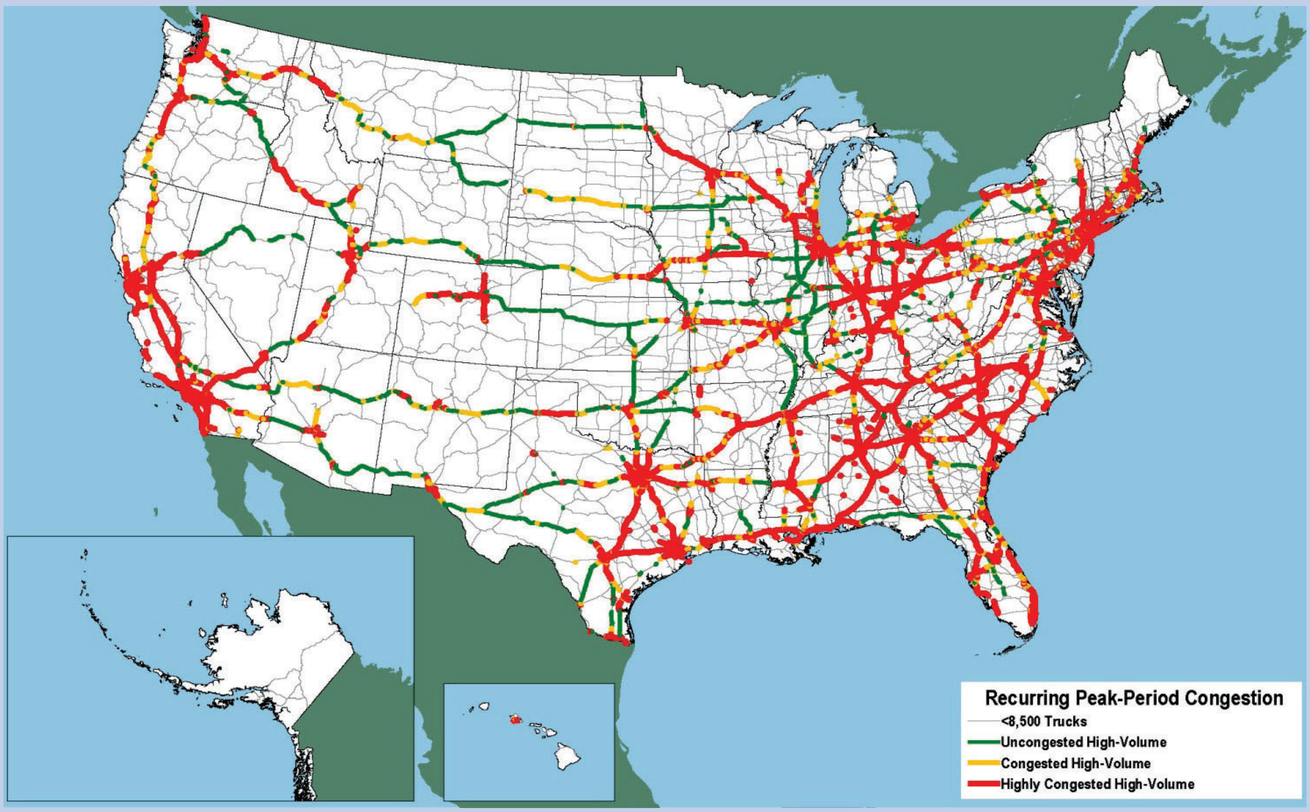
Sources: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Performance Measurement Program, 2011 (map), 2012 (table data).

highways. Reduced truck travel speeds most commonly occur in large metropolitan areas, but can also occur at international border crossings and gateways, in mountainous areas that require trucks to climb steep inclines, and in areas frequently prone to poor visibility driving conditions.

Projections of Future Congestion

Though in many cases congestion on many high-volume NHS truck routes in various large metropolitan areas is already severe, particularly during peak periods, the congestion could become much more severe in terms of its geographic scope and impact on major intercity corridors and metropolitan areas if network capacity remains unchanged. *Exhibit 5-5* shows a map indicating where this peak-period congestion on high-volume truck portions of the NHS could take place in 2040 . Peak-period congestion is projected to create stop-and-go conditions on 23,500 miles of the NHS (over six times as many miles as in 2007) and traffic slower than posted speed limits on an additional 7,200 miles of the NHS (nearly twice as many miles as in 2007).

Exhibit 5-5 Peak-Period Congestion on High-Volume Truck Portions of the National Highway System, 2040



Note: High-volume truck portions of the National Highway System carry more than 8,500 trucks per day, including freight-hauling long-distance trucks, freight-hauling local trucks, and other trucks with six or more tires. Highly congested segments are stop-and-go conditions with volume/service flow ratios greater than 0.95. Congested segments have reduced traffic speeds with volume/service flow ratios between 0.75 and 0.95. The volume/service flow ratio is estimated using the procedures outlined in the HPMS Field Manual, Appendix N.

Sources: U.S. Department of Transportation, Federal Highway Administration, Office of Highway Policy Information, Highway Performance Monitoring System, and Office of Freight Management and Operations, Freight Analysis Framework, version 3.2, 2010.

Congestion Mitigation and Reliability Improvement

Efforts to mitigate congestion and improve reliability can take place by improving service on existing roads, introducing pricing schemes, or enhancing information provided to drivers. Frequently, several of the strategies presented below are applied in tandem, mitigating a number of congestion sources in a holistic manner. More detail can be found at http://www.fhwa.dot.gov/congestion/toolbox/index.htm.

Improve Service on Existing Roads

- **Traffic Incident Management** is a planned and coordinated process shared by public and private sector partners to detect, respond to, and remove traffic incidents and restore traffic capacity as safely and quickly as possible.
- **Arterial Management** improves travel throughout entire communities by coordinating traffic signals through timing and access management. Arterial roadways are high-capacity roads to deliver traffic from collector roads to freeways, and between urban centers.
  - *Traffic Signal Timing* can produce benefit-cost ratios as high as 40 to 1. The costs for retiming traffic signals are generally very small, but provide substantial benefit.
  - *Access Management* is the proactive management of vehicular access points to land parcels adjacent to roadways. State and local governments can control access to facilities by increasing the distance between traffic signals; constructing fewer driveways spaced farther apart to allow for more orderly merging; constructing dedicated left- and right-turn lanes, indirect left-turn and U-turn lanes, and roundabouts to keep through-traffic flowing; constructing two-way left-turn lanes and non-traversable, raised medians; and managing right-of-way for future widening, good sight distance, access location, and other access-related issues.
- **Freeway Management and Traffic Operations** involves applying the appropriate policies, strategies, and actions to mitigate any potential impacts resulting from the intensity, timing, and location of travel and to reduce congestion. The Traffic Management Center (TMC) is often the hub of most freeway management systems.
- **Active Transportation and Demand Management** (ATDM) is the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Through the use of archived data and/or predictive methods, traffic flow is managed and traveler behavior is influenced in real time to achieve operational objectives, such as preventing or delaying breakdown conditions, improving safety, promoting sustainable travel modes, reducing emissions, or maximizing system efficiency.
- **Road Weather Management** allows weather events and their impacts on roads to be viewed as predictable, nonrecurring incidents that affect safety, congestion, and productivity. Advisory strategies provide information on prevailing and predicted conditions to both transportation managers and motorists, such as posting fog warnings on dynamic message signs or listing flooded routes on websites. Control strategies alter roadway devices (messages, timing of signals, etc.) to permit or restrict traffic flow and regulate roadway capacity, such as reducing speed limits with variable speed limit signs and modifying traffic signal timing. Treatment strategies supply resources to roads to minimize or eliminate weather impacts, the most common of which are application of sand, salt, and anti-icing chemicals to pavements to improve traction and prevent ice bonding.
- **Planned Special Events Traffic Management** allows agencies to develop and deploy the operational strategies, traffic control plans, protocols, procedures, and technologies needed to control traffic and share real-time information with other stakeholders on the day of an event. Planned special events cause congestion and unexpected delays to travelers by increasing traffic demand or reducing roadway capacity (e.g., street closures for parades).

Pricing

- **Congestion Pricing**, sometimes referred to as value pricing or peak-period pricing, involves charging relatively higher prices for travel during peak periods. It is identical to the technique used in many other sectors of the economy to respond to peak-use demands. Congestion pricing entails fees or tolls for road use that vary with the level of congestion. Introducing congestion pricing to highway facilities brings

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transportation supply and demand into balance and keeps the lanes congestion free. Fees are typically assessed electronically to eliminate delays associated with manual toll collection facilities.

Add Capacity

- **Easing Bottlenecks** is necessary when a road is at capacity and the flow of traffic is disrupted. The capacity of a road is determined by a number of factors, including the number and width of lanes and shoulders, merge areas at interchanges, and roadway alignment (grades and curves). Minimizing the impacts of or eliminating bottlenecks is one of the most effective ways to reduce congestion.

Better Work Zones

- **Work Zone Management** can have a positive impact on preventing or relieving congestion by aggressively anticipating and mitigating congestion caused by highway work zones. Solutions can come from fundamental changes in the way projects are planned, estimated, designed, bid, and constructed.

Travel Options

- **Travel Demand Management** involves strategies to provide travelers with effective travel choices such as work location, route, time, and mode. Managing both the growth of and periodic shifts in traffic demand are necessary elements of managing traffic congestion.
- **Transportation Choices** such as accessibility to transit, car-sharing or bicycle/pedestrian facilities helps alleviate congestion on the Nation's road network. By promoting the use of transit or bicycle/pedestrian facilities, the use of fewer cars during peak travel times also improves air quality in communities with close proximity to major highways.

Traveler Information

- The **511** telephone number was designated for traveler information services by the Federal Communications Commission in 2001 and assigned to public transportation agencies for implementing services throughout the United States. FHWA is working cooperatively with FTA, the American Association of State Highway and Transportation Officials, the American Public Transportation Association, the Intelligent Transportation Society of America, and the members of the 511 Coalition to establish more 511 travel information services throughout the United States.
- **Travel Time Message Signs** are dynamic signs located near roadways that give motorists the estimated time it will take them to get to the next one or two significant destinations.
- **National Traffic and Road Closure Information** is provided to travelers and freight shippers to broadcast current weather, road, and traffic conditions.
- **Real-Time System Management Information** is a real-time information system that provides the capability to monitor traffic and travel conditions on major highways. This information enables drivers to make informed decisions. FHWA is supporting the deployment of the Real-Time System Management Information Program so that all States are able to broadcast information to travelers.
- The **Cross-Town Improvement Project** (C-TIP) combines real-time travel time information and freight shipper congestion information to optimize the flow of freight within a metropolitan area. Cross-town truck traffic is coordinated using both public and private traffic and freight data to reduce empty truck bobtail (tractor without trailer) moves between railroad terminals and freight distribution facilities. The system uses four components that include an information exchange, wireless update capability, real-time traffic monitoring, and dynamic routing applications to deliver up-to-the-minute information regarding roadway conditions, travel speeds, and predicted travel times. This information is passed to the freight traveler to deliver enhanced traveler information and predictive travel times for freight pick-up and delivery routes in urban areas.

Transit System Performance

Basic goals shared by all transit operations include minimizing travel times, making efficient use of vehicle capacity, and providing reliable performance. The Federal Transit Administration (FTA) collects data on average speed, how full the vehicles are (utilization), and how often they break down (mean distance between failures) to characterize how well transit service meets these goals. These data are reported here; safety data are reported in Chapter 4.

More subjective customer satisfaction issues, such as how easy it is to access transit service (accessibility) and how well that service meets a community's needs, are harder to measure. Data from the FHWA 2009 National Household Travel Survey, reported here, provide some insights but are not available on an annual basis and so do not support time series analysis.

New technology has allowed progressive transit agencies to report service metrics on their Web sites. Because this is a relatively new practice, measures that are standardized across the industry have not yet been developed. Industry associations are beginning to address this issue, but for now there is no generally recognized set of standards.

The following analysis presents data on average operating speeds, average number of passengers per vehicle, average percentage of seats occupied per vehicle, average distance traveled per vehicle, and mean distance between failures for vehicles. Average speed, seats occupied, and distance between failures address efficiency and customer service issues; passengers per vehicle and miles per vehicle are primarily efficiency measures. Financial efficiency metrics, including operating expenditures per revenue mile or passenger mile, are discussed in Chapter 6.

FTA Livable Communities Outcomes and Performance Measures

Modal Network	*Demand Response*
1. Increased access to convenient and affordable transportation choices	• Increase the number of transit boardings reported by urbanized area transit providers from 10.0 billion in 2011 to 10.5 billion in 2016. • Increase the number of transit boardings reported by rural area transit providers from 141 million in 2011 to 160 million in 2016. • Increase transit's market share among commuters to work in at least 10 of the top 50 urbanized areas by population, as compared to 2010 market share levels.
2. Improved access to transportation for people with disabilities and older adults	• Increase the number of key transit rail stations verified as accessible and fully compliant from 522 in 2010 to 560 in 2016.

Average Operating (Passenger-Carrying) Speeds

Average vehicle operating speed is an approximate measure of the speed experienced by transit riders; it is not a measure of the operating speed of transit vehicles between stops. More specifically, average operating speed is a measure of the speed passengers experience from the time they enter a transit vehicle to the time they exit it, including dwell times at stops. It does not include the time passengers spend waiting or transferring. Average vehicle operating speed is calculated for each mode by dividing annual vehicle revenue miles by annual vehicle revenue hours for each agency in each mode, weighted by the passenger miles traveled (PMT) for each mode, as reported to the National Transit Database (NTD). In cases where an agency contracts with

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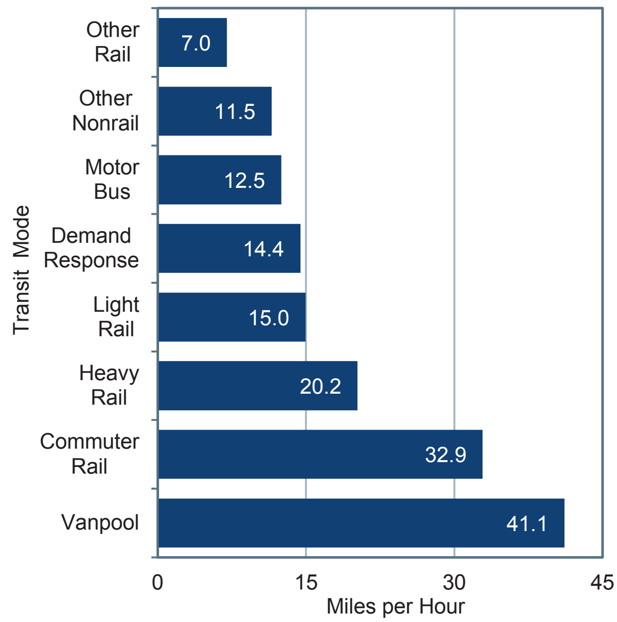
a service provider and provides the service directly, the speeds for each of the services within a mode are calculated and weighted separately. The results of these average speed calculations are presented in *Exhibit 5-6*.

The average speed of a transit mode is strongly affected by the number of stops it makes. Motor bus service, which typically makes frequent stops, has a relatively low average speed. In contrast, commuter rail has high sustained speeds between infrequent stops, and thus a relatively high average speed. Vanpools also travel at high speeds, usually with only a few stops at each end of the route. Modes using exclusive guideway can offer more rapid travel time than similar modes that do not. Heavy rail, which travels exclusively on dedicated guideway, has a higher average speed than light rail, which often shares its guideway with mixed traffic. These average speeds have not changed significantly over the last decade.

Exhibit 5-6 Average Speeds for Passenger-Carrying Transit Modes, 2010



Notes: Other Nonrail includes Público, trolleybus, and demand taxi; Other Rail includes Alaska railroad, automated guideway, cable car, inclined plane, and monorail.

Source: National Transit Database.

Vehicle Use

Vehicle Occupancy

Exhibit 5-7 shows vehicle occupancy by mode for selected years from 2000 to 2010. Vehicle occupancy is calculated by dividing PMT by vehicle revenue miles (VRMs), resulting in the average number of people carried in a transit vehicle. There has been little change in vehicle occupancy between 2000 and 2010 indicating sustained ridership levels across all types of transit.

Taking into account that vehicle capacities differ by mode, *Exhibit 5-8* shows the 2010 vehicle occupancy as a percentage of the seating capacity for an average vehicle in each mode (based on the average number of seats reported per vehicle in 2010: vanpool, 11; heavy rail, 59; light rail, 57; trolleybus, 45; ferryboat, 385; commuter rail, 96; motor bus, 33; demand response, 12). For example, the average full-size bus seats 33 people and, as shown in *Exhibit 5-7*, the average occupancy for a bus in 2010 was 10.7 riders. This occupancy, as a percentage of seating capacity, is 32.5 percent. Some modes also have substantial standing capacity that is not considered here, but which can allow the measure of the percentage of seats occupied to exceed 100 percent for a full vehicle.

Although, on average, it appears that there is excess capacity in all these modes, commuting patterns make it difficult to fill vehicles returning to the suburbs from downtown employment centers during the morning rush hours and, likewise, to fill vehicles going downtown in the evening rush. Vehicles also tend to be relatively empty at the beginning and ends of their routes. For many commuter routes, a vehicle that is crush-loaded (i.e., filled to maximum capacity) on part of the trip may still only achieve an average occupancy of around 35 percent (as shown by analysis of the Washington Metropolitan Area Transit Authority peak-period data).

Exhibit 5-7 Unadjusted Vehicle Occupancy: Passengers per Transit Vehicle, 2000–2010

Mode	2000	2002	2004	2006	2008	2010
Rail						
Heavy Rail	23.9	22.6	23.0	23.2	25.7	25.3
Commuter Rail	37.9	36.7	36.1	36.1	35.7	34.2
Light Rail	26.1	23.9	23.7	25.5	24.1	23.7
Other Rail[1]	8.4	8.4	10.4	8.4	9.3	10.7
Nonrail						
Motor Bus	10.7	10.5	10.0	10.8	10.8	10.7
Demand Response	1.3	1.2	1.3	1.3	1.2	1.2
Ferryboat	120.1	112.1	119.5	130.7	118.1	119.3
Trolleybus	13.8	14.1	13.3	13.9	14.3	13.6
Vanpool	6.6	6.4	5.9	6.3	6.3	6.0
Other Nonrail[2]	7.3	7.9	5.8	7.8	8.2	7.4

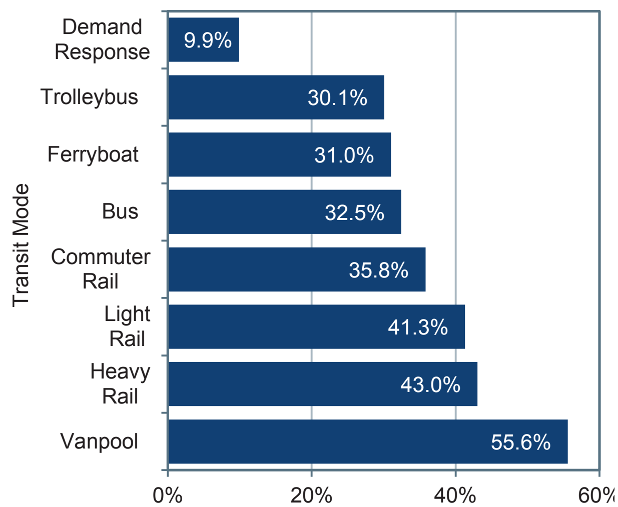
[1] *Alaska railroad, automated guideway, cable car, inclined plane, and monorail.*

[2] *Aerial tramway and Público.*

Source: National Transit Database.

Another issue that makes it hard to fully use vehicle capacity is called "bunching." If a stop has a particularly large number of passengers, the servicing vehicle takes longer to load increasing the spacing between it and the previous vehicle. This not only means the vehicle's next stop will have more riders due to the longer interval, but that there will be a shorter interval between it and the vehicle behind it. This compounds the problem by slowing the vehicle more and speeding up the vehicle behind it. Soon the vehicles become bunched up, causing longer wait times for some passengers and inconsistent in-vehicle volumes with some being overcrowded and others underutilized. This situation is common and difficult to mitigate.

Exhibit 5-8 Average Seat Occupancy Calculations for Passenger-Carrying Transit Modes, 2010



Note: Some modes also have substantial standing capacity that is not considered here, but which can allow the measure of the percentage of seats occupied to exceed 100 percent for a full vehicle.

Source: National Transit Database.

Revenue Miles per Active Vehicle (Service Use)

Vehicle service use, the average distance traveled per vehicle in service, can be measured by VRMs. *Exhibit 5-9* provides vehicle service use by mode for selected years from 2000 to 2010. Heavy rail, generally offering long hours of frequent service, had the highest vehicle use during this period. Vehicle service use for light rail, and to a lesser extent for vanpool and demand response, shows an increasing trend. Vehicle service use for other nonrail modes appears to be relatively stable over the past few years with no apparent trends in either direction.

Exhibit 5-9 Vehicle Service Utilization: Vehicle Revenue Miles per Active Vehicle by Mode

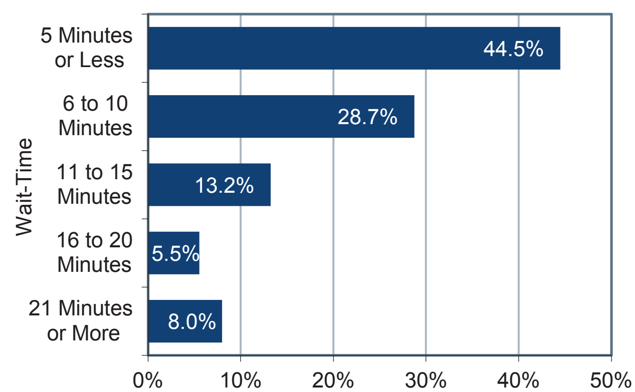
	Thousands of Revenue Vehicle Miles						Average Annual Rate of Change
Mode	2000	2002	2004	2006	2008	2010	2010/2000
Rail							
Heavy Rail	55.6	55.1	57.0	57.2	57.7	56.6	0.2%
Commuter Rail	42.1	43.9	41.1	43.0	45.5	45.1	0.7%
Light Rail	32.5	41.1	39.9	39.9	44.1	42.5	2.7%
Nonrail							
Motor Bus	28.0	29.9	30.2	30.2	30.3	29.7	0.6%
Demand Response	17.9	21.1	20.1	21.7	21.3	20.0	1.1%
Ferryboat	24.1	24.4	24.9	24.8	21.9	24.9	0.3%
Vanpool	12.9	13.6	14.1	13.7	14.3	15.5	1.8%
Trolleybus	18.9	20.3	21.1	19.1	18.7	20.4	0.8%

Source: National Transit Database.

Frequency and Reliability of Service

The frequency of transit service varies considerably according to location and time of day. Transit service is more frequent in urban areas and during rush hours—namely, where and when the demand for transit is highest. Studies have found that transit passengers consider the time spent waiting for a transit vehicle to be less well spent than the time spent traveling in a transit vehicle. The higher the degree of uncertainty in waiting times, the less attractive transit becomes as a means of transportation and it will attract fewer users. Further, when scheduled service is offered less frequently, reliability becomes more important to users.

Exhibit 5-10 Distribution of Passengers by Wait-Time

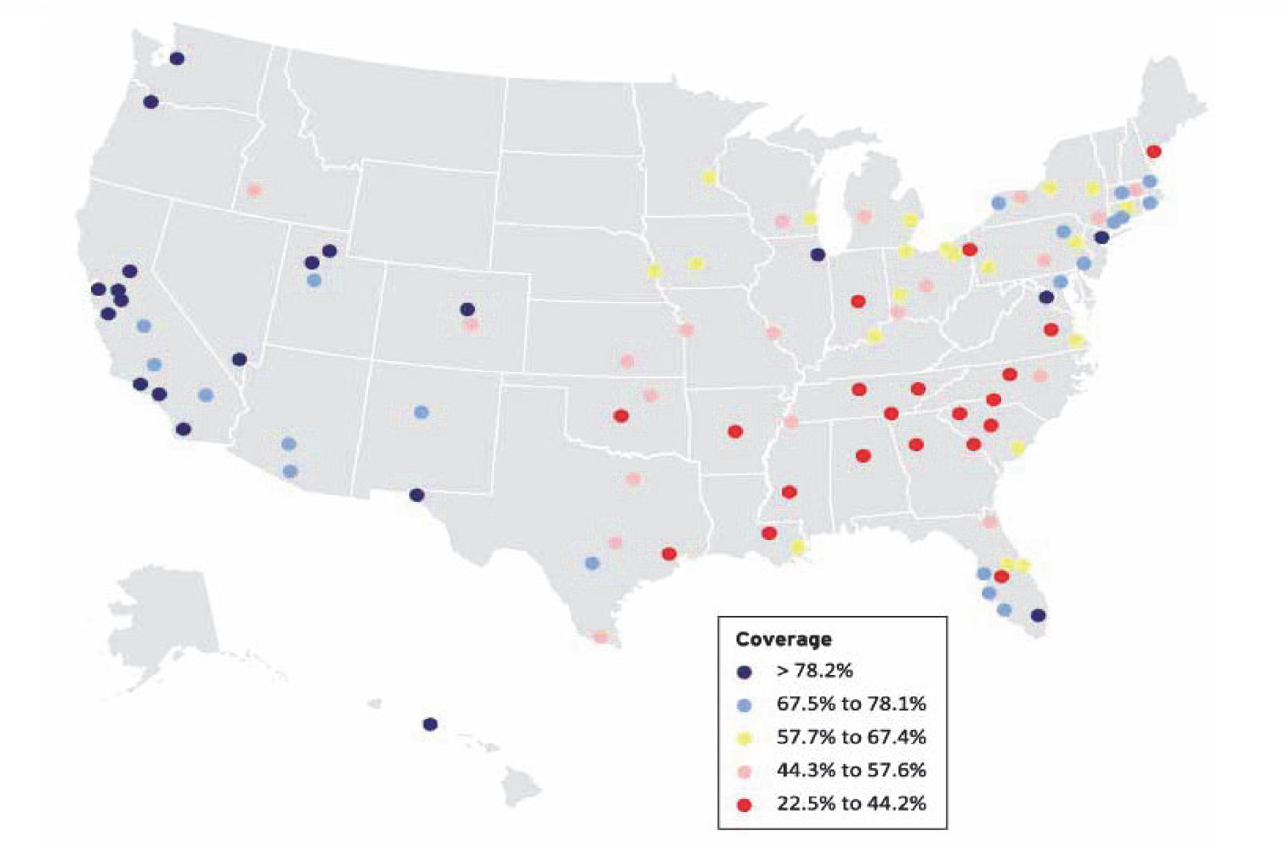


Source: National Household Travel Survey, FHWA, 2009.

Exhibit 5-10 shows findings on wait-times from the 2009 FHWA National Household Travel Survey (NHTS), the most recent nationwide survey of this information. The NHTS found that 44.5 percent of all passengers who ride transit wait 5 minutes or less and 73.2 percent wait 10 minutes or less. The NHTS also found that 8.0 percent of all passengers wait 21 minutes or more. A number of factors influence passenger wait-times, including the frequency of service, the reliability of service, and passengers' awareness of timetables. These factors are also interrelated. For example, passengers may intentionally arrive earlier for service that is infrequent, compared with equally reliable services that are more frequent. Overall, waiting times of 5 minutes or less are clearly associated with good service that is either frequent, reliably provided according to a schedule, or both. Waiting times of 5 to 10 minutes are most likely consistent with adequate levels of service that are both reasonably frequent and generally reliable. Waiting times of 21 minutes or more indicate that service is likely less frequent or less reliable.

Access to transit service varies by location. *Exhibit 5-11* shows the share of working-age residents that have access to transit in 100 selected metro areas. The study evaluated census block groups and counted block groups with at least one transit stop within three-fourths of a mile of their population-weighted centroid as having access. Cities in the Western U.S. tend to enjoy higher rates of coverage while those in the southeast tend to have a lower percentage of residents with access to transit.

Exhibit 5-11 **Share of Working-Age Residents With Access to Transit, 100 Metropolitan Areas**



Source: Brookings Institution, Missed Opportunity: Transit and Jobs in Metropolitan America*, May 2011 report citing Brookings Institution analysis of transit agency data and Nielson Pop-Facts 2010 data.*

Mean distance between failures, as shown in *Exhibit 5-12*, has declined 14 percent since 2004 to 6,601 miles. The average distance between failures is calculated by adding all mechanical failures to all other failures and dividing VRMs by this total number of failures. The stability shown in the graph indicates that the number of unscheduled delays due to mechanical failure of transit vehicles has not increased. The FTA does not collect data on delays due to guideway conditions; this would include congestion for roads and slow zones (due to system or rail problems) for track.

Exhibit 5-12 **Mean Distance Between Failures, 2004–2010**

Source: National Transit Database.

System Coverage: Urban Directional Route Miles

The extent of the Nation's transit system is measured in directional route miles, or simply "route miles." Route miles measure the distance covered by a transit route; even though opposite-direction transit routes may use the same road or track, they are counted separately. Data associated with route miles are not collected for demand response and vanpool modes because these transit modes do not travel along specific predetermined routes. Route miles data are also not collected for jitney services because these transit modes often have highly variable route structures.

Exhibit 5-13 shows directional route miles by mode over the past 10 years. Growth in both rail (27.3 percent) and nonrail (20.7 percent) route miles is evident over this period. The average 6.0 percent rate of annual growth for light rail clearly outpaces the rate of growth for all other modes.

Exhibit 5-13 Transit Urban Directional Route Miles, 2000–2010

	Route Miles						Average Annual Rate of Change
Transit Mode	**2000**	**2002**	**2004**	**2006**	**2008**	**2010**	**2010/2000**
Rail	**9,222**	**9,484**	**9,782**	**10,865**	**11,270**	**11,735**	**+2.4%**
Commuter Rail [1]	6,802	6,923	6,968	7,930	8,219	8,590	+2.4%
Heavy Rail	1,558	1,572	1,597	1,623	1,623	1,617	+0.4%
Light Rail	834	960	1,187	1,280	1,397	1,497	+6.0%
Other Rail [2]	29	30	30	31	30	30	+0.5%
Nonrail [3]	**196,858**	**225,820**	**216,619**	**223,489**	**212,801**	**237,580**	**+1.9%**
Bus	195,884	224,838	215,571	222,445	211,664	236,434	+1.9%
Ferryboat	505	513	623	620	682	690	+3.2%
Trolleybus	469	468	425	424	456	456	-0.3%
Total	**206,080**	**235,304**	**226,401**	**234,354**	**224,071**	**249,314**	**+1.9%**
Percent Nonrail	95.5%	96.0%	95.7%	95.4%	95.0%	95.3%	

[1] *Includes Alaska rail.*

[2] *Automated guideway, inclined plane, cable car, and monorail.*

[3] *Excludes jitney, Público, and vanpool.*

Source: National Transit Database.

System Capacity

Exhibit 5-14 provides reported VRMs for both rail and nonrail modes. These numbers are of interest because they show the actual number of miles traveled by each mode in revenue service. VRMs provided by both bus services and rail services show consistent growth, with light rail and vanpool miles growing somewhat faster than the other modes. Overall, the number of VRMs has increased by 22.5 percent since 2000.

Transit system capacity, particularly in cross-modal comparisons, is typically measured by capacity-equivalent VRMs. These measure the distance traveled by transit vehicles in revenue service and adjust them by the passenger-carrying capacity of each transit vehicle type, with the average carrying capacity of motor bus vehicles representing the baseline. To calculate capacity-equivalent VRMs, the number of revenue miles for a vehicle is multiplied by the bus-equivalent capacity of that vehicle. Thus, a heavy rail car that seats 2.5 times more people than a full-size bus provides 2.5 capacity-equivalent miles for each revenue mile it travels.

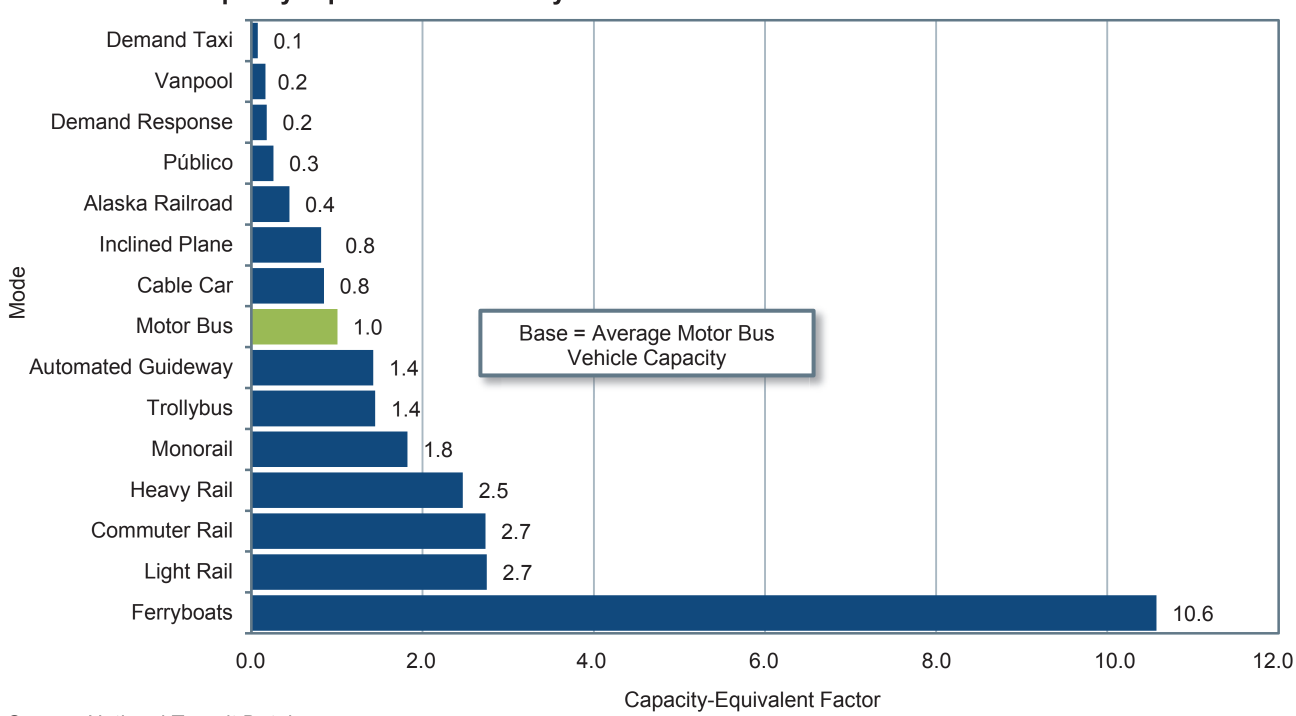
Exhibit 5-14 Rail and Nonrail Vehicle Revenue Miles, 2000–2010

	Miles (Millions)						Average Annual Rate of Change
Transit Mode	2000	2002	2004	2006	2008	2010	2010/2000
Rail	**879**	**925**	**963**	**997**	**1,054**	**1,056**	**1.9%**
Heavy Rail	578	603	625	634	655	647	1.1%
Commuter Rail	248	259	269	287	309	315	2.4%
Light Rail	51	60	67	73	86	92	6.0%
Other Rail	2	3	2	3	3	2	1.7%
Nonrail	**2,322**	**2,502**	**2,586**	**2,674**	**2,841**	**2,863**	**2.1%**
Motor Bus	1,764	1,864	1,885	1,910	1,956	1,917	0.8%
Demand Response	452	525	561	607	688	718	4.7%
Vanpool	62	71	78	110	157	181	11.3%
Ferryboat	2	3	3	3	3	3	5.0%
Trolleybus	14	13	13	12	11	12	-1.8%
Other Nonrail	28	26	46	32	25	32	1.5%
Total	**3,201**	**3,427**	**3,549**	**3,671**	**3,895**	**3,920**	**2.0%**

Source: National Transit Database.

The 2010 capacity-equivalent factors for each mode are shown in *Exhibit 5-15*. Unadjusted VRMs for each mode are multiplied by a capacity-equivalent factor in order to calculate capacity-equivalent VRMs. These factors are equal to the average full-seating and full-standing capacities of vehicles in active service for each transit mode divided by the average full-seating and full-standing capacities of all motor bus vehicles in active service. The average capacity of the national motor bus fleet changes slightly from year to year as the proportion of large, articulated, and small buses varies. The average capacity of the bus fleet in 2010 was 39 seated and 23 standing for a total of 62 riders.

Exhibit 5-15 Capacity-Equivalent Factors by Mode



Source: National Transit Database.

Total capacity-equivalent VRMs are shown in *Exhibit 5-16*. Showing the most rapid expansion in capacity-equivalent VRMs in the period from 2000 to 2010 was vanpools, followed by light rail, demand response, and then commuter rail. Total capacity-equivalent revenue miles increased from 3,954 million in 2000 to 4,845 million in 2010, an increase of 22.5 percent.

Exhibit 5-16 Capacity-Equivalent Vehicle Revenue Miles, 2000–2010

	Vehicle Miles (Millions)						Average Annual Rate of Change
Transit Mode	**2000**	**2002**	**2004**	**2006**	**2008**	**2010**	**2010/2000**
Rail	**2,046**	**2,274**	**2,413**	**2,681**	**2,799**	**2,714**	**2.9%**
Heavy Rail	1,321	1,469	1,546	1,648	1,621	1,599	1.9%
Commuter Rail	595	652	685	832	940	860	3.8%
Light Rail	127	150	179	197	235	252	7.1%
Other Rail	3	3	3	4	3	3	-1.1%
Nonrail	**1,908**	**2,037**	**2,064**	**2,118**	**2,152**	**2,131**	**1.1%**
Motor Bus	1,764	1,864	1,885	1,910	1,956	1,917	0.8%
Demand Response	76	100	101	121	115	124	5.1%
Vanpool	11	15	15	22	27	30	10.0%
Ferryboat	30	32	32	37	32	35	1.4%
Trolleybus	20	20	20	19	16	17	-1.6%
Other Nonrail	7	7	12	10	6	8	1.3%
Total	**3,954**	**4,311**	**4,478**	**4,800**	**4,951**	**4,845**	**2.1%**

Source: National Transit Database.

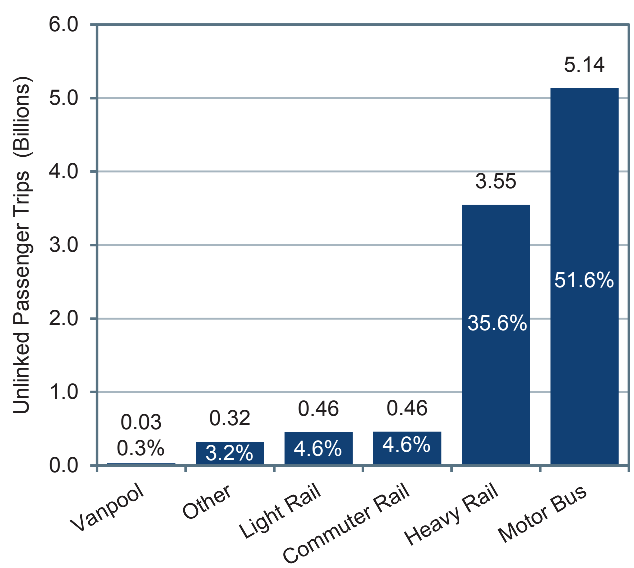
Ridership

There are two primary measures of transit ridership: unlinked passenger trips and PMT. An unlinked passenger trip, sometimes called a boarding, is defined as a journey on *one* transit vehicle. PMT is calculated on the basis of unlinked passenger trips and estimates of average trip length. Either measure provides an appropriate time series because average trip lengths, by mode, have not changed substantially over time. Comparisons across modes, however, may differ substantially depending on which measure is used due to large differences in the average trip length for the different modes.

Exhibit 5-17 and *Exhibit 5-18* show the distribution of unlinked passenger trips and PMT by mode. In 2010, urban transit systems provided 9.9 billion unlinked trips and 52.6 billion PMT across all modes. Heavy rail and motorbus modes continue to be the largest segments of both measures. Commuter rail supports relatively more PMT due to its greater average trip length (23.4 miles compared to 4.0 for bus, 4.6 for heavy rail, and 4.8 for light rail).

Exhibit 5-19 provides total PMT for selected years between 2000 and 2010, showing steady growth in all the major modes. Demand response, light rail, and vanpool modes grew at the fastest rates. Growth in demand response (up 4.0 percent per year) may be a response to demand from the growing number of

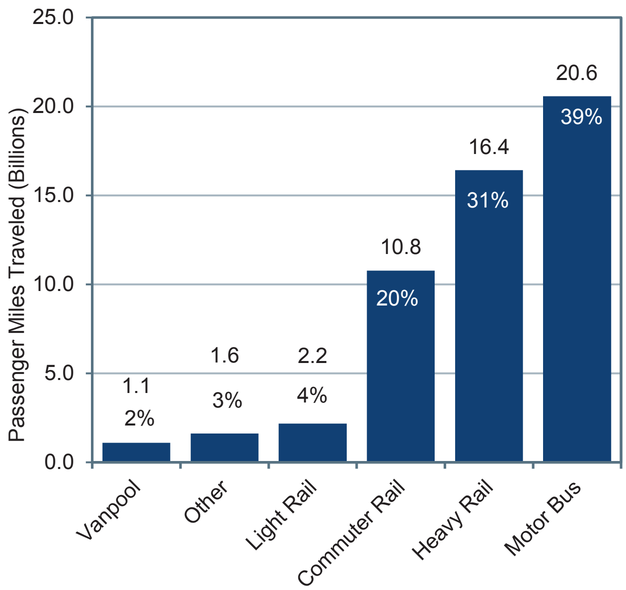
Exhibit 5-17 Unlinked Passenger Trips (Total in Billions and Percent of Total) by Mode, 2010



Note: Other includes Alaska railroad, automated guideway, cable car, demand response, ferryboat, inclined plane, monorail, Público, trolleybus, and demand taxi.

Source: National Transit Database.

Exhibit 5-18 Passenger Miles Traveled (Total in Billions and Percent of Total) by Mode, 2010



Note: "Other" includes Alaska railroad, automated guideway, cable car, demand response, ferryboat, inclined plane, monorail, Público, trolleybus, and demand taxi.

Source: National Transit Database.

elderly citizens. Light rail (up 5.0 percent per year) enjoyed increased capacity during this period due to expansions and addition of new systems. Vanpool's rapidly increasing popularity (up 10.3 percent per year), particularly the surge between 2006 and 2008 (up 20 percent per year), can be partially attributed to rising gas prices—regular gasoline sold for more than $4 per gallon in July of 2008. FTA has also encouraged vanpool reporting during this period, successfully enrolling a large number of new vanpool systems to report to NTD.

Exhibit 5-20 shows the complex relationship among an index of rolling 12 months' transit ridership, gasoline prices, and employment rates.

On the most basic level, the effectiveness of transit operations can be gauged by the demand for transit services. People choose to use transit if they perceive that it meets their needs as well as, or better than, the alternatives. These choices occur in an economic context in which the need for transportation and the cost of that transportation are constantly changing due to factors that have very little to do with the characteristics of transit.

Exhibit 5-19 Transit Urban Passenger Miles, 2000–2010

	Passenger Miles (Millions)						Average Annual Rate of Change
Transit Mode	**2000**	**2002**	**2004**	**2006**	**2008**	**2010**	**2010/2000**
Rail	**24,604**	**24,617**	**25,667**	**26,972**	**29,989**	**29,380**	**1.8%**
Heavy Rail	13,844	13,663	14,354	14,721	16,850	16,407	1.7%
Commuter Rail	9,400	9,500	9,715	10,359	11,032	10,774	1.4%
Light Rail	1,340	1,432	1,576	1,866	2,081	2,173	5.0%
Other Rail[1]	20	22	22	25	26	26	2.8%
Nonrail	**20,497**	**21,328**	**20,879**	**22,533**	**23,723**	**23,247**	**1.3%**
Motor Bus	18,807	19,527	18,921	20,390	21,198	20,570	0.9%
Demand Response	588	651	704	753	844	874	4.0%
Vanpool	407	455	459	689	992	1,087	10.3%
Ferryboat	298	301	357	360	390	389	2.7%
Trolleybus	192	188	173	164	161	159	-1.9%
Other Nonrail[2]	205	206	265	176	138	169	-1.9%
Total	**45,101**	**45,945**	**46,546**	**49,504**	**53,712**	**52,627**	**1.6%**
Percent Rail	54.6%	53.6%	55.1%	54.5%	55.8%	55.8%	

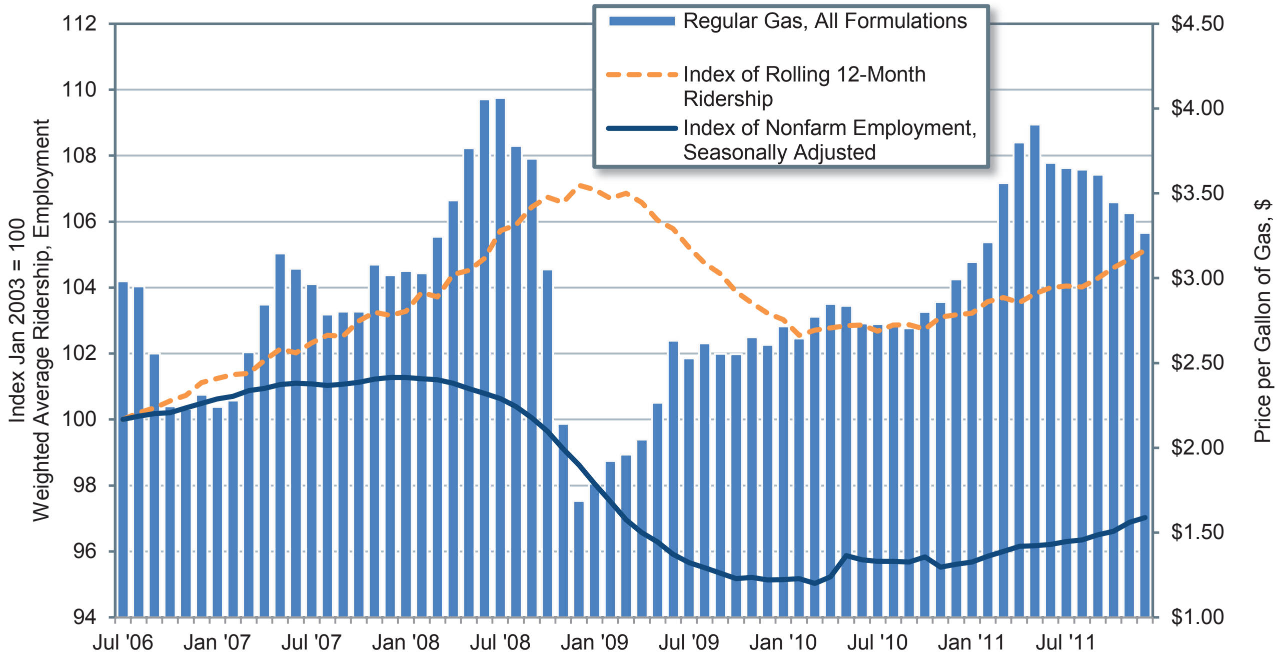
[1] *Alaska railroad, automated guideway, cable car, inclined plane, and monorail.*

[2] *Aerial tramway and Público.*

Source: National Transit Database.

The relationship between employment and transit is well established. According to the May 2007 APTA report *A Profile of Public Transportation Passenger Demographics and Travel Characteristics Reported in On-Board Surveys:* "Commuting to work is the most common reason a person rides public transportation, accounting for 59.2 percent of all transit trips reported in on-board surveys." It would follow from this that

Exhibit 5-20 **Transit Ridership versus Employment, 2006–2011**

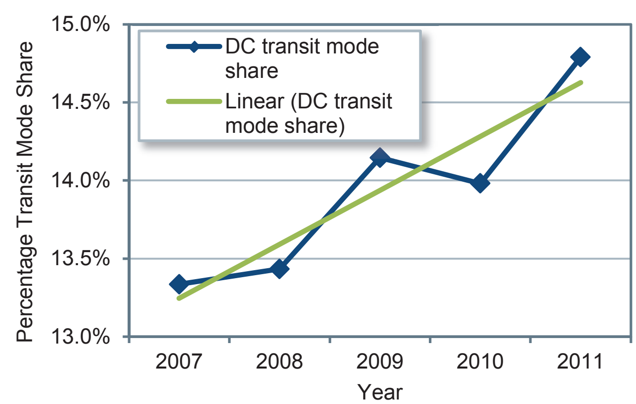


Source: National Transit Database, U.S. Energy Information Administration's Gas Pump Data History, and Bureau of Labor Statistics' Employment Data.

transit ridership should drop off in times of high unemployment and, in fact, until 2008 the correlation between transit ridership and employment levels was so strong that FTA corrected ridership to account for employment levels. From early 2007 through summer of 2008, however, transit ridership increased in the absence of employment growth. This anomaly may be due to dramatic increases in the price of gas during this period; gas prices increased from around $2.35 per gallon to over $4.00 per gallon. Since the start of 2009, gas prices have eased and then grown again in a similar but more gradual pattern, but without influencing transit ridership in the same way (perhaps due to a concurrent decline in employment). Since 2010, ridership has once again been tracking employment levels but has retained some of its 2007–2008 gains. In July of 2011, transit ridership was up 5 percent over its July 2006 level while employment was still down 3 percent from its July 2006 level.

If gas prices are the causal factor here, one would expect to see transit taking a greater market share of commuting rides to work. This would be a different effect than there being more riders due to an increase in the number of commuters overall, which would not imply a change in market share. To test this hypothesis, FTA examined American Community Survey (ACS) data for 2007 through 2011 for the Washington, DC, metropolitan area. ACS data for 2008–2011, presented in *Exhibit 5-21*, show a gain in transit mode share during this period, which supports the explanation that gas prices are having a major impact on transit ridership.

Exhibit 5-21 **Washington, DC, Transit Mode Share, 2007–2011**



Source: U.S. Census Bureau, American Community Survey.

CHAPTER 6

Finance

Highway Finance

This chapter provides data and analysis of finance trends for highways and transit across all levels of government. The revenue sources that support investments in highways and bridges are outlined first, followed by a presentation of total highway expenditures and then highway capital outlays only. A separate section of the chapter presents finance trends for transit systems.

In February 2009, the American Recovery and Reinvestment Act (Recovery Act) provided additional funds for transportation and other programs. Transportation received over $48 billion for expenditures in highways, transit, rail, aviation, and other transportation modes. The Department's broad recovery goals reflect those of the Recovery Act, primarily (1) creating and preserving jobs and promoting economic recovery and (2) investing in infrastructure that has long-term economic benefits. The effects of the additional funds will be evident in the revenue and expenditure levels and trends presented; these effects are referenced and explained where relevant.

Revenue Sources for Highways

The revenue generated from all levels for government for highways in 2010 was $221.0 billion, as shown in *Exhibit 6-1.* Of the total revenue, the Federal government contributed $59.0 billion, State governments contributed $109.0 billion and Local governments contributed $53.1 billion.

Exhibit 6-1 Government Revenue Sources for Highways, 2010

	Highway Revenue, Billions of Dollars				
Source	**Federal**	**State**	**Local**	**Total**	**Percent**
User Charges[1]					
Motor-Fuel Taxes	$26.1	$30.3	$1.0	$57.4	26.0%
Motor-Vehicle Taxes and Fees	$2.6	$22.8	$1.5	$26.9	12.2%
Tolls	$0.0	$7.9	$1.7	$9.6	4.3%
Subtotal	**$28.7**	**$61.0**	**$4.1**	**$93.8**	**42.5%**
Other					
Property Taxes and Assessments	$0.0	$0.0	$9.4	$9.4	4.3%
General Fund Appropriations[2]	$29.6	$7.2	$21.8	$58.6	26.5%
Other Taxes and Fees	$0.6	$6.6	$4.9	$12.2	5.5%
Investment Income and Other Receipts	$0.0	$8.2	$5.6	$13.9	6.3%
Bond Issue Proceeds	$0.0	$25.9	$7.1	$33.0	14.9%
Subtotal	**$30.2**	**$48.0**	**$48.9**	**$127.1**	**57.5%**
Total Revenues	**$59.0**	**$109.0**	**$53.1**	**$221.0**	**100.0%**
Funds Drawn From (or Placed in) Reserves[3]	($11.9)	($3.7)	($0.1)	($15.7)	-7.1%
Total Expenditures Funded During 2010	**$47.1**	**$105.3**	**$52.9**	**$205.3**	**92.9%**

[1] Amounts shown represent only the portion of user charges that are used to fund highway spending; a portion of the revenue generated by motor-fuel taxes, motor-vehicle taxes and fees, and tolls is used for mass transit and other nonhighway purposes. Gross receipts generated by user charges totaled $120.4 billion in 2010.

[2] The $29.6 billion shown for Federal reflects $14.7 billion transferred from the General Fund to the Highway Trust Fund in 2010, as well as the expenditure in 2010 of $11.9 billion of the funding authorized for use on highways by the Recovery Act. The remainder supported expenditures by the FHWA and other Federal agencies that were not paid for from the Highway Trust Fund.

[3] The $11.9 billion figure shown for Federal reflects the increase in the balance of the Highway Account of the Highway Trust Fund from approximately $8.9 billion at the beginning of the year to approximately $20.7 billion at the end of the year. Without the $14.7 billion transfer of general funds to the Highway Account, this balance would have declined. It should be noted that while the increase in the Highway Account balance in 2010 and the amount of Recovery Act funds expended for highways during 2010 both round to $11.9 billion, this is entirely coincidental. Recovery Act funding was authorized from the General Fund, and has no direct impact on the Highway Trust Fund.

Sources: Highway Statistics 2010, Table HF-10, and unpublished FHWA data.

These revenues were raised from user charges and a number of other sources (other taxes, investment income and debt financing). Federal, State and local governments provide a different mix of revenue sources. A significant share of Federal and State revenues are from user charges. Most of the local revenues are from other sources, particularly General Fund Appropriations.

As shown in *Exhibit 6-1*, all levels of government combined spent $205.3 billion for highways in 2010. The net difference of $15.7 billion between the total revenues generated during the year and the expenditures during the year increased the reserves available for use in future years. For example, the $11.9 billion difference between total Federal revenues and expenditures represents the increase in the cash balance of the Highway Account of the Highway Trust Fund (HTF) in 2010. While cash balances for some States and localities rose during the year, others fell. Collectively, cash balances in dedicated highway accounts at the State level rose by $3.7 billion, while highway accounts at the local level grew by $0.1 billion.

The total proceeds to the Highway Account of the HTF from dedicated excise taxes and other receipts have fallen below annual expenditures for several years. Transfers of Federal General Fund to the Highway Account were made in 2008, 2009 and 2010 to keep the account solvent. Public Law 111-147 transferred $14.7 billion from the General Fund to the Highway Account of the HTF in 2010. In the absence of this transfer, the balance of the Highway Account would have declined rather than increased.

Q&A

Do the user charges reflected in *Exhibit 6-1* include all revenues generated by motor-fuel taxes, motor-vehicle taxes and fees, and tolls in 2010?

No. The $93.8 billion identified as highway-user charges in *Exhibit 6-1* represents only 77.8 percent of total highway-user revenue, defined as all revenue generated by motor-fuel taxes, motor-vehicle taxes, and tolls. *Exhibit 6-2* shows that combined highway-user revenue collected in 2010 by all levels of government totaled $120.4 billion.

In 2010, $14.7 billion of highway-user revenue was used for transit, and $11.9 billion was used for other purposes, such as ports, schools, collection costs, and general government activities. The $0.4 billion shown as Federal highway-user revenue used for other purposes reflects the difference between total collections in 2010 and the amounts deposited into the HTF during FY 2010. Much of this difference is attributable to the proceeds of 0.1 cent of the motor-fuel tax being deposited into the Leaking Underground Storage Tank trust fund.

Exhibit 6-2 Disposition of Highway-User Revenue by Level of Government, 2010

	Revenue, Billions of Dollars			
	Federal	State	Local	Total
Highways	$28.7	$61.0	$4.1	$93.8
Transit	$5.9	$7.7	$1.0	$14.7
Other	$0.4	$11.3	$0.2	$11.9
Total Collected	**$35.1**	**$80.0**	**$5.3**	**$120.4**

Sources: Highway Statistics 2010, Table HF-10, and unpublished FHWA data.

The $5.9 billion shown as Federal highway-user revenue used for transit includes deposits into the Transit Account of the HTF, as well as deposits into the Highway Account of the HTF that States elected to use for transit purposes.

The $29.6 billion identified as Federal General Fund Appropriations in *Exhibit 6-1* includes these $14.7 billion of transferred funds as well as the 2010 expenditure of $11.9 billion authorized under the Recovery Act. The remaining $3.0 billion represents highway-related expenditures of a variety of Federal agencies for activities that are not supported by the Federal Highway Trust Fund, including certain programs of the FHWA (such as a portion of the Emergency Relief Program) and the National Highway Traffic Safety Administration, some direct expenditures by other Federal agencies for roads that they own (see Chapter 12 for a discussion of transportation on Federal lands), and payments to States and local governments under some programs managed by other agencies for which road improvements are an eligible activity. As a result of the unusually high reliance on general funds to support highways at the Federal level in 2010, user charges accounted for less than half of the Federal revenue for highways. User charges accounted for a higher share of State revenues (55.8 percent), consisting of motor fuel taxes ($30.3 billion), motor vehicle taxes and fees ($22.8 billion) and tolls ($7.9 billion). Of the other sources, bond proceeds provided the largest revenue for the States ($25.9 billion).

American Recovery and Reinvestment Act

In February 2009, the American Recovery and Reinvestment Act authorized $48.1 billion for programs administered by the Department of Transportation. The goal was to stimulate the economy by supporting jobs in the construction sector and to invest in critical transportation infrastructure. Of this total, $27.5 billion was appropriated for FHWA. In addition, highway and bridge projects were eligible to compete for Office of the Secretary of Transportation's Supplemental Discretionary Grant for a National Surface Transportation System program, later referred to as the TIGER I program.

Most of the obligation authority for the highway infrastructure investment funds was distributed to the States by the Federal-aid allocation formula. States were required to obligate these funds to specific projects by the end of September 2010 to avoid losing them. The expenditure of these funds is occurring gradually as States are reimbursed by the FHWA for their expenditures over the life of these projects as the work is completed, which is consistent with how the regular Federal-aid highway program operates. The statistics presented in this Chapter reflect expenditures on a cash basis rather than obligations, so the Recovery Act may continue to have an impact on the reported highway revenues and expenditures for several years.

The period over which cash expenditures are incurred for an individual project depends on the length of time it takes to complete the work, which can vary by project type. During 2010, $11.9 billion of Recovery Act funds were expended for highway-related activities.

Could the Recovery Act project selection process be affecting the spending rates for the regular Federal-aid Highway Program?

Q&A

States were under tight deadlines to obligate Recovery Act funds by September 30, 2010, and their progress in obligating these funds was closely monitored by FHWA; less emphasis was placed on the obligation of regular Federal-aid program funds, provided that regular deadlines were met. In addition, States were not required to contribute matching funds for projects funded from the Recovery Act, providing an additional incentive to use these funds before the regular Federal-aid highway program funds. The financial data presented in this report are presented on a cash basis; to the extent that delays in obligating funds for a given project within a given fiscal year affected the start date for that project, this could influence the timing of the cash expenditures associated with that project.

Much of the Recovery Act funding was directed to projects that could be implemented relatively quickly in order to maximize their short-term impacts on employment. This reduced the pool of such potential projects under consideration by States for funding from their regular Federal-aid highway program, which could have affected the relative mix of projects selected. To the extent that some States obligated their Federal-aid highway program funds to projects of longer duration than usual, this would have tended to slow down the average Federal cash spending rate, since cash reimbursements are made to States only after work has been completed. To the extent that such a phenomenon has occurred it could have dampened the initial impacts of Recovery Act funding, but increased the duration of these impacts.

Many States do not permit local governments to impose motor-fuel or motor-vehicle taxes; if allowed they cap them at relatively low levels. Therefore, at the local government level, only $4.1 billion (7.8 percent) of highway funding was provided by user charges in 2010. General fund appropriations contributed $21.8 billion (41.1 percent) toward total local highway revenues, while property taxes generated $9.4 billion (17.7 percent).

The "Investment Income and Other Receipts" category in *Exhibit 6-1* includes development fees and special district assessments. Other private sector investment in highways would also be reflected in this category, to the extent that such investment is captured in State and local accounting systems.

Private Sector Financing

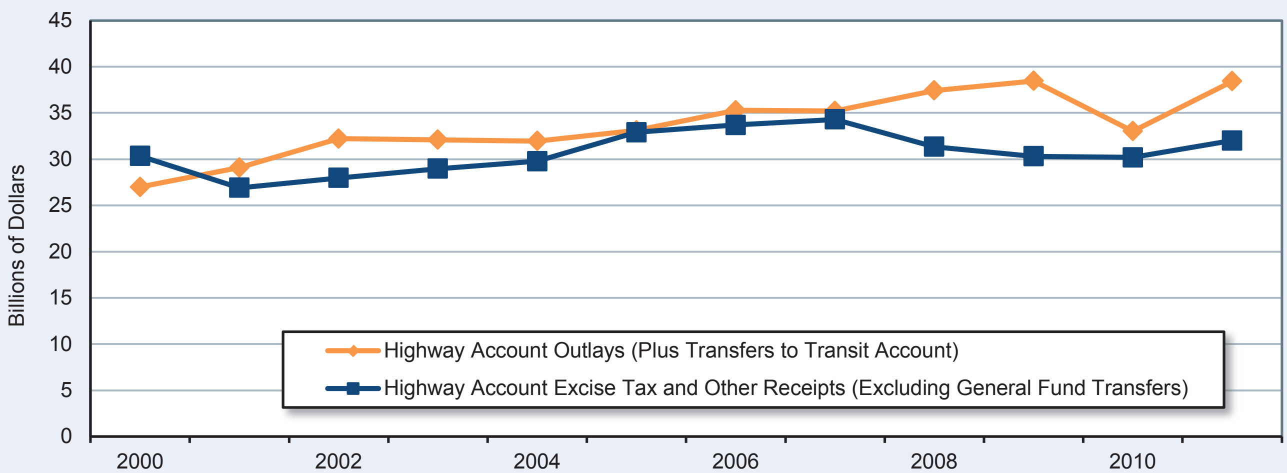
Financing for highways comes from both the public and private sectors. The private sector has increasingly played a role in the delivery of highway infrastructure, but the vast majority of funding is still provided by the public sector. The financial statistics presented in this chapter are predominantly drawn from State reports based on State and local accounting systems. Figures in these systems can include some private sector investment; where it does, these amounts are generally classified as "other receipts." For additional information on private sector investment in highways, see http:/ www.fhwa.dot.gov/ipd/p3/index.htm.

How long has it been since excise tax revenue deposited into the Highway Account exceeded expenditures?

The last time that annual net receipts credited to the Highway Account of the HTF exceeded annual expenditures from the Highway Account was in 2000. As shown in *Exhibit 6-3*, for each year since 2000, total annual receipts to the Highway Account from excise taxes and other income (such as interest income and motor carrier safety fines and penalties) have been lower than the annual expenditures from the Highway Account (including amounts transferred to the Transit Account).

To help maintain a positive cash balance in the HTF, three transfers from the General Fund to the HTF were legislatively mandated in FY 2008, FY 2009, and FY 2010. From FY 2007 to FY 2010 gross excise tax receipts from gasoline, diesel and special motor fuels, tires, trucks and trailers, and the heavy vehicle use tax all declined. In 2011, the receipts increased for the first time since 2007. The outlays also increased, retaining the gap between tax revenue deposited in the HTF and the expenditures.

Exhibit 6-3 Highway Trust Fund Highway Account Receipts and Outlays, Fiscal Years 2000–2011



Sources: Highway Statistics, various years, Tables FE-210 and FE-10.

Revenue Trends

Since the passage of the Federal-Aid Highway Act of 1956 and the establishment of the HTF, user charges such as motor-fuel and motor-vehicle tax receipts have consistently provided the majority of the combined revenues raised for highway and bridge programs by all levels of government.

Exhibit 6-4 shows the trends in revenue for all governments for the period 2000 to 2010. Total revenues have increased on average by 5.4 percent per year between 2000 and 2010. The annual growth in revenue from motor fuel and vehicle taxes was only 1.1 percent per year. General Fund appropriation and Bond issue proceeds each increased by over eleven percent per year. The increase in the General Fund appropriations was particularly strong in 2008 and 2010, when transfers were made from the General Fund to keep the HTF solvent, following many years of cash outlays exceeding cash receipts and running down the reserve balance.

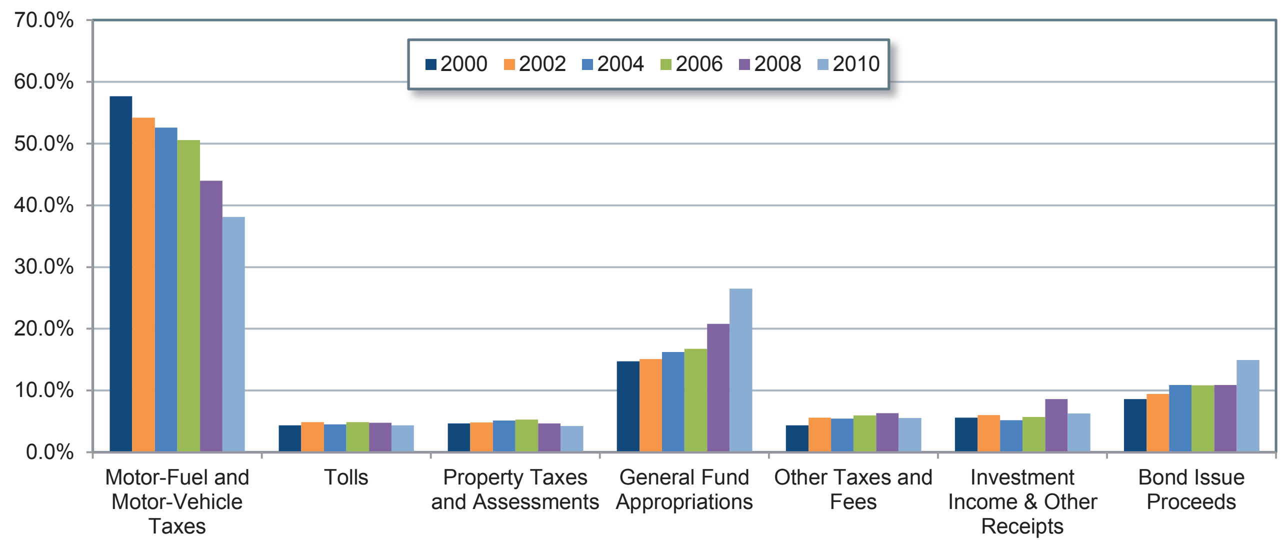
The graph in *Exhibit 6-4* illustrates the percentage of revenue from different sources to the total revenue each year for the period 2000 to 2010. The percentage of revenue from user charges, particularly motor fuel and vehicle taxes, has declined over time, whereas the General Fund appropriations and bond proceeds have increased.

Motor fuel tax revenues are sensitive to changes in VMT and fuel efficiency. The growth in VMT over the decade from 2000 to 2010 has averaged 0.8 percent per year in contrast to the previous 10 years, when

VMT increased by 2.9 percent per year. In 2008 and 2009, VMT declined each year; 2010 VMT is lower than the 2007 level. Motor fuel efficiency has also increased over the period from 2000 to 2010; from an average of 16.9 miles traveled per gallon of fuel consumed to 17.4 miles traveled per gallon of fuel consumed (*Highway Statistics*, Table VM-1). Some States compensated for declines in user revenues by increasing fuel tax rates and other motor vehicle taxes. The weighted average State gasoline motor fuel tax increased from 19.96 cents per gallon in 2000 to 21.82 cents per gallon in 2010. Similarly, the diesel motor fuel tax rate increased from 19.96 cents per gallon to 22.36 cents per gallon (*Highway Statistics*, Table MF-205). The increases in tax rates were more evident after 2005. The decline in user revenues was offset by increasing revenues from other sources. Transfers from the General Fund helped to sustain the HTF at the level necessary to support the federal spending levels specified in the SAFETEA-LU. Bond issue proceeds increased from $20.9 billion in 2008 to $33.0 billion in 2010, a 58 percent increase in two years.

Exhibit 6-4 Government Revenue Sources for Highways, 2000–2010

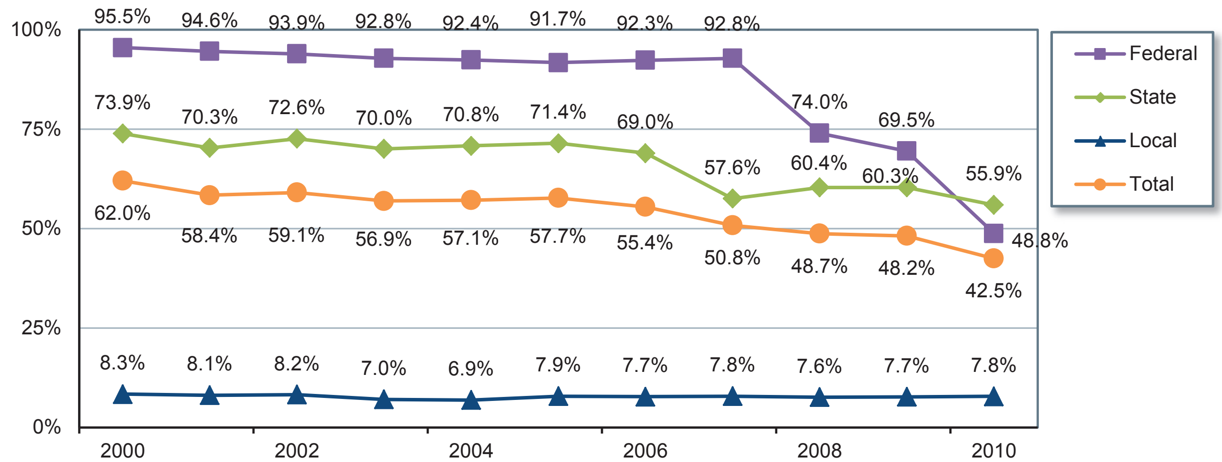
	Highway Revenue, Billions of Dollars						Annual Rate of Change
Source	**2000**	**2002**	**2004**	**2006**	**2008**	**2010**	**2010/2000**
Motor-Fuel and Motor-Vehicle Taxes	$75.6	$73.1	$76.4	$85.4	$84.7	$84.3	1.1%
Tolls	$5.7	$6.6	$6.6	$8.3	$9.1	$9.6	5.3%
Property Taxes and Assessments	$6.1	$6.5	$7.5	$9.0	$9.0	$9.4	4.4%
General Fund Appropriations	$19.3	$20.3	$23.6	$28.3	$40.0	$58.6	11.8%
Other Taxes and Fees	$5.7	$7.5	$7.9	$10.1	$12.2	$12.2	7.8%
Investment Income & Other Receipts	$7.3	$8.1	$7.6	$9.7	$16.6	$13.9	6.6%
Bond Issue Proceeds	$11.3	$12.7	$15.8	$18.3	$20.9	$33.0	11.3%
Total Revenues	**$131.1**	**$134.8**	**$145.3**	**$169.0**	**$192.6**	**$221.0**	**5.4%**



Sources: Highway Statistics, various years, Tables HF-10A and HF-10.

Exhibit 6-5 shows the change in the share of highway revenue derived from user charges by the level of government. The share has declined for all levels of government combined from 2000 to 2010, but the decline has been more significant for the Federal user charges, from 95.5 percent to 48.8 percent. As noted earlier, the declines since 2007 can be attributed in part from General Fund transfers to the HTF, as well as general funds provided through the Recovery Act. State user revenue share has declined to 42.5 percent from 62.0 percent. User charges have also declined as a share of local government revenue.

Exhibit 6-5 **Percent of Highway Revenue Derived From User Charges, Each Level of Government, 2000–2010**



Sources: Highway Statistics, various years, Tables HF-10A and HF-10.

Highway Expenditures

Highway expenditures by all levels of government combined totaled $205.3 billion in 2010, as seen in *Exhibits 6-1* and *6-5*. *Exhibit 6-6* breaks down the Federal, State and Local expenditures by type. The rows "Funding Sources for Capital Outlay" and "Funding Sources for Total Expenditures" indicate the level of government that provided the funding for those expenditures. These expenditures represent cash outlays, not authorizations or obligations of funds. (The terms "expenditures", "spending" and "outlays" are used interchangeably in this report.)

While the Federal government funded $47.1 billion of highway expenditures in 2010, direct Federal spending on capital outlay, maintenance, administration and research amounted to only $3.6 billion (1.8 percent of all highway expenditures). The remaining $43.5 billion was in the form of transfers to State and local governments.

State governments combined $42.1 billion of Federal funds, $81.9 billion of State funds and $3.1 billion of local funds to support direct expenditures of $127.1 billion (61.9 percent of all highway expenditures). Local governments directly spent $1.4 billion of Federal funds, $23.4 billion of State funds and $49.8 billion of local funds on highways, totaling $74.6 billion (36.3 percent of all highway expenditures).

Types of Highway Expenditures

As shown in *Exhibit 6-6*, in 2010 all levels of government spent $100.0 billion (48.8 percent) of highway expenditures on capital outlay. Additional information on types of capital outlay and the distribution of capital outlay by type of highway facility is presented later in this chapter. Combined spending on maintenance and traffic services of $48.8 billion represented 23.7 percent on total highway expenditures.

The majority of Federal funding for highways goes for capital outlay rather than noncapital expenditures, which are funded primarily by State and local governments. The Federal government funded 44.3 percent of capital outlay in 2008, but only 22.9 percent of total highway expenditures.

In terms of direct highway expenditures by expending agency, State expenditures represent a majority of total spending for most expenditure types. The exceptions are the "maintenance" and "highway patrol and safety categories" identified in *Exhibit 6-6*. Local governments spent $20.1 billion on maintenance in 2010, which is 60.2 percent of total maintenance spending by all levels of government combined. Local governments also spent $9.4 billion on highway patrol and safety expenditures, representing 52.0 percent of combined spending on these activities by all levels of government.

Exhibit 6-6 **Direct Expenditures for Highways, by Expending Agencies and by Type, 2010**

	Highway Expenditures (Billions of Dollars)				
	Federal	**State**	**Local**	**Total**	**Percent**
Expenditures by Type					
Capital Outlay	**$0.8**	**$72.6**	**$26.8**	**$100.2**	**48.8%**
Noncapital Expenditures					
Maintenance	$0.3	$13.0	$20.1	$33.4	16.2%
Highway and Traffic Services	$0.0	$9.0	$6.5	$15.4	7.5%
Administration	$2.4	$8.8	$4.9	$16.2	7.9%
Highway Patrol and Safety	$0.0	$8.7	$9.4	$18.1	8.8%
Interest on Debt	$0.0	$7.0	$2.9	$9.8	4.8%
Subtotal	**$2.7**	**$46.4**	**$43.7**	**$92.9**	**45.2%**
Total, Current Expenditures	**$3.6**	**$119.0**	**$70.5**	**$193.0**	**94.0%**
Bond Retirement	**$0.0**	**$8.1**	**$4.1**	**$12.3**	**6.0%**
Total, All Expenditures	**$3.6**	**$127.1**	**$74.6**	**$205.3**	**100.0%**
Funding Sources for Capital Outlay					
Funded by Federal Government*	*$0.8*	*$42.1*	*$1.4*	*$44.4*	***44.3%***
Funded by State or Local Govts*	*$0.0*	*$30.4*	*$25.4*	*$55.8*	*55.7%*
Total	***$0.8***	***$72.5***	***$26.8***	***$100.2***	***100.0%***
Funding Sources for Total Expenditures					
Funded by Federal Government*	*$3.6*	*$42.1*	*$1.4*	*$47.1*	***22.9%***
Funded by State Governments*	*$0.0*	*$81.9*	*$23.4*	*$105.3*	*51.3%*
Funded by Local Governments*	*$0.0*	*$3.1*	*$49.8*	*$52.9*	*25.8%*
Total	***$3.6***	***$127.1***	***$74.6***	***$205.3***	***100.0%***

** Amounts shown in italics are provided to link this table back to revenue sources shown in Exhibit 6-1. These are nonadditive to the rest of the table, which classifies spending by expending agency.*

Sources: Highway Statistics 2010, Table HF-10, and unpublished FHWA data.

Historical Expenditure and Funding Trends

Exhibit 6-7 breaks out expenditures by type since 2000. The largest percentage increases related to debt service, as bond retirement expenditures grew at an average annual rate of 9.2 percent from 2000 to 2010, while interest on debt grew an average annual rate of 7.9 percent. Total highway expenditures grew by 5.3 percent per year over this period in nominal dollar terms, while capital outlay rose at an average annual rate of 5.0 percent, capital expenditures becoming a smaller share of total expenditures.

Exhibit 6-7 **Expenditures for Highways by Type, All Units of Government, 2000–2010**

	Highway Expenditures, Billions of Dollars						Annual Rate of Change
	2000	**2002**	**2004**	**2006**	**2008**	**2010**	**2010/2000**
Expenditure Type							
Capital Outlay	$61.3	$68.2	$70.3	$80.2	$90.4	$100.2	5.0%
Maintenance and Traffic Services	$30.6	$33.2	$36.3	$40.8	$45.9	$48.8	4.8%
Administration	$10.0	$10.7	$12.7	$13.1	$17.8	$16.2	4.9%
Highway Patrol and Safety	$11.0	$11.7	$14.3	$14.7	$17.3	$18.1	5.1%
Interest on Debt	$4.6	$5.4	$5.8	$6.6	$8.5	$9.8	7.9%
Total, Current Expenditures	**$117.6**	**$129.1**	**$139.5**	**$155.5**	**$180.0**	**$193.0**	**5.1%**
Bond Retirement	$5.1	$6.8	$8.0	$8.1	$8.6	$12.3	9.2%
Total, All Expenditures	**$122.7**	**$135.9**	**$147.5**	**$163.5**	**$188.5**	**$205.3**	**5.3%**

Sources: Highway Statistics, various years, Tables HF-10A and HF-10.

Highway Expenditure Terminology

The classification of the revenue and expenditure items in this report is based on definitions contained in *A Guide to Reporting Highway Statistics*, the instructional manual for States providing financial data for the *Highway Statistics* publication.

- "Capital outlay" consists of those expenditures associated with highway improvements. Improvements include land acquisition and other right-of-way costs; preliminary and construction engineering; new construction, reconstruction, resurfacing, rehabilitation, and restoration; and installation of guardrails, fencing, signs, and signals.
- "Maintenance" includes routine and regular expenditures required to keep the highway surface, shoulders, roadsides, structures, and traffic control devices in usable condition. This includes completing spot patching and crack sealing of roadways and bridge decks and maintaining and repairing highway utilities and safety devices such as route markers, signs, guardrails, fence, signals, and highway lighting. (Other definitions of maintenance are used by different organizations. Some resurfacing, restoration, and rehabilitation projects that meet this report's definition of capital outlay might be classified as maintenance activities in internal State or local accounting systems.)
- "Highway and traffic services" include activities designed to improve the operation and appearance of the roadway. This includes items such as the operation of traffic control systems, snow and ice removal, highway beautification, litter pickup, mowing, toll collection, and air quality monitoring.
- "Current expenditures" includes all highway expenditures except for bond retirement. When looking at cash outlays for a particular year, total expenditures is more relevant, as it measures the full scope of highway-related activity. However, when summing expenditures across years, it is sometimes more appropriate to use current expenditures. For example, if bonds were issued to pay for a capital project, and retired 20 years later, then summing total expenditures over 20 years would effectively capture this transaction twice, as both the initial capital expenditure and the retirement of the bonds would be included.
- "Non-capital expenditures" consists of all current expenditures except for capital outlay. It includes maintenance, highway and traffic services, administration, highway law enforcement, safety programs, and interest on debt.

Exhibit 6-8 shows that Federal funding for highways grew more quickly from 2000 to 2010 than did State or local funding. The portion of total highway expenditures rose from 22.4 percent to 22.9 percent over this period, while the Federally funded share of highway capital outlay rose from 42.6 percent to 44.3 percent. As noted earlier in this chapter, the Federal expenditure figures for 2010 include $11.9 billion funded by the Recovery Act. As Federally funded highway expenditures grew by only $7.3 billion from 2008 to 2010 (from $39.8 billion to $47.1 billion), this indicates that cash-basis expenditures funded from other Federal sources declined over this 2-year period.

Despite budgetary pressures relating to the recent recession, State funding for highways increased from $96.6 billion in 2008 to $105.3 billion in 2010. Local government funding also increased slightly during this period, from $52.2 billion in 2008 to $52.9 billion in 2010.

Exhibit 6-8 Funding for Highways by Level of Government, 2000–2010

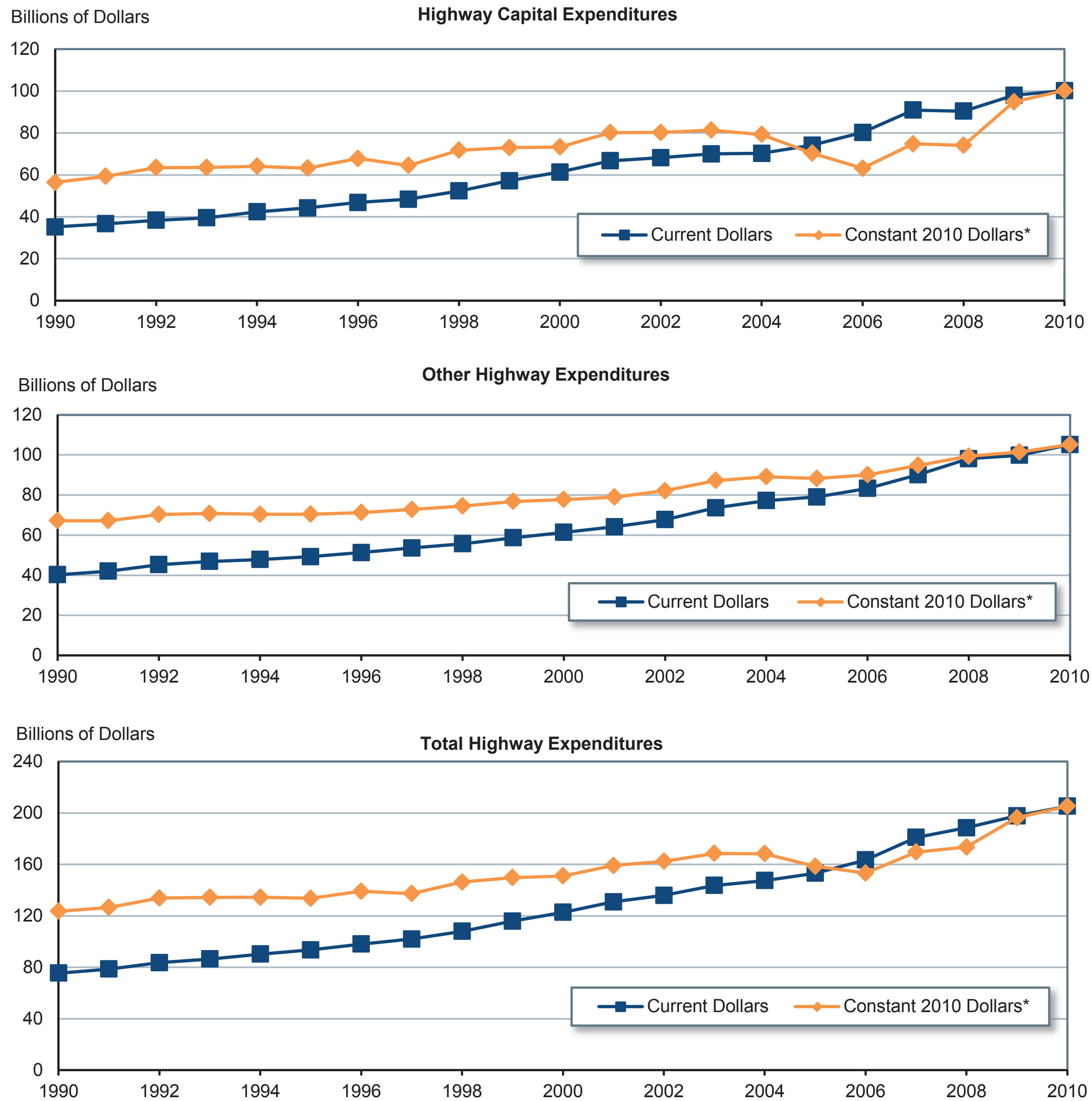
	Highway Funding, Billions of Dollars						Annual Rate of Change
	2000	2002	2004	2006	2008	2010	2010/2000
Capital Outlay							
Funded by Federal Government	$26.1	$31.5	$30.8	$34.6	$37.6	$44.4	5.4%
Funded by State or Local Govt's	$35.2	$36.7	$39.5	$45.6	$52.8	$55.8	4.7%
Total	**$61.3**	**$68.2**	**$70.3**	**$80.2**	**$90.4**	**$100.2**	**5.0%**
Federal Share	**42.6%**	**46.1%**	**43.8%**	**43.1%**	**41.6%**	**44.3%**	
Total Expenditures							
Funded by Federal Government	$27.5	$32.8	$33.1	$36.3	$39.8	$47.1	5.5%
Funded by State Governments	$62.7	$69.0	$72.8	$77.4	$96.6	$105.3	5.3%
Funded by Local Governments	$32.6	$34.1	$41.6	$49.8	$52.2	$52.9	5.0%
Total	**$122.7**	**$135.9**	**$147.5**	**$163.5**	**$188.5**	**$205.3**	**5.3%**
Federal Share	**22.4%**	**24.1%**	**22.4%**	**22.2%**	**21.1%**	**22.9%**	

Sources: Highway Statistics, various years, Tables HF-10A and HF-10.

Constant Dollar Expenditures

Exhibits 6-9 and 6-10 display time series data on highway expenditures in both current (nominal) and constant (real) 2010 dollars. While there have been periods of decrease in constant dollars for both highway capital expenditures and total highway expenditures, both reached an all-time high in 2010.

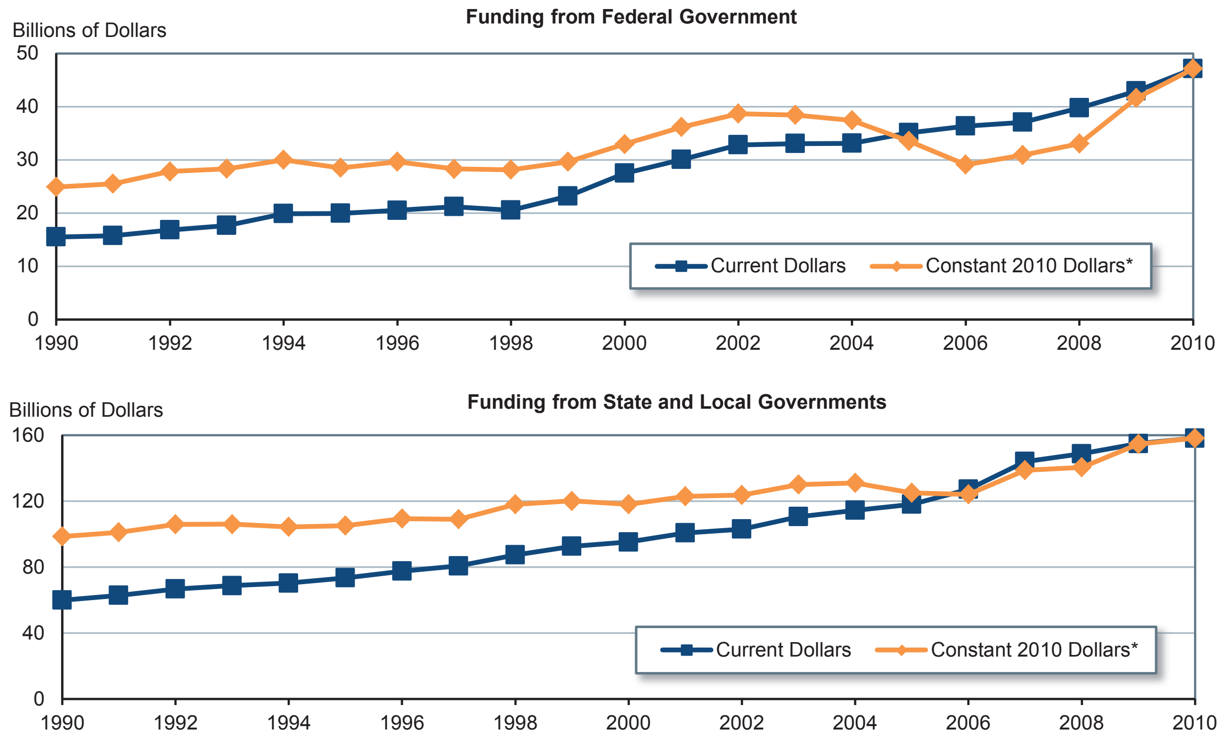
Exhibit 6-9 Highway Capital, Noncapital, and Total Expenditures in Current and Constant 2010 Dollars, All Units of Government, 1990–2010



* Constant dollar conversions for highway capital expenditures were made using the FHWA BPI through the year 2006, and the FHWA NHCCI in subsequent years. Constant dollar conversions for other types of highway spending were made using the Bureau of Labor Statistics' CPI.

Sources: Highway Statistics, various years, Tables HF-10A, HF-10, PT-1; http://www.bls.gov/cpi/.

Exhibit 6-10 **Highway Expenditures Funded by Federal and Non-Federal Sources, in Current and Constant 2010 Dollars, 1990–2010**



*Constant dollar conversions for highway capital expenditures were made using the FHWA BPI through the year 2006, and the FHWA NHCCI in subsequent years. Constant dollar conversions for other types of highway spending were made using the Bureau of Labor Statistics' CPI.

Sources: Highway Statistics, various years, Tables HF-10A, HF-10, PT-1; http://www.bls.gov/cpi/.

For the 20-year period from 1990 to 2010, highway capital spending increased at an average annual rate of 2.9 percent in constant dollar terms, slightly above the 2.6 percent annual constant dollar growth rate for total highway expenditures. Constant dollar spending grew more quickly over the 10-year period from 2000 to 2010, rising 3.2 percent annually for capital expenditures and 3.1 percent annually for total highway expenditures.

From 1990 to 2010, Federally funded highway expenditures increased at an average annual rate of 3.2 percent in constant dollar terms; State and local constant dollar expenditures grew more slowly, rising by 2.4 percent per year on average. For the 10-year period from 2000 to 2010, Federally funded constant dollar highway expenditures rose 3.6 percent per year, compared to a 3.0 percent average annual increase for State and local governments.

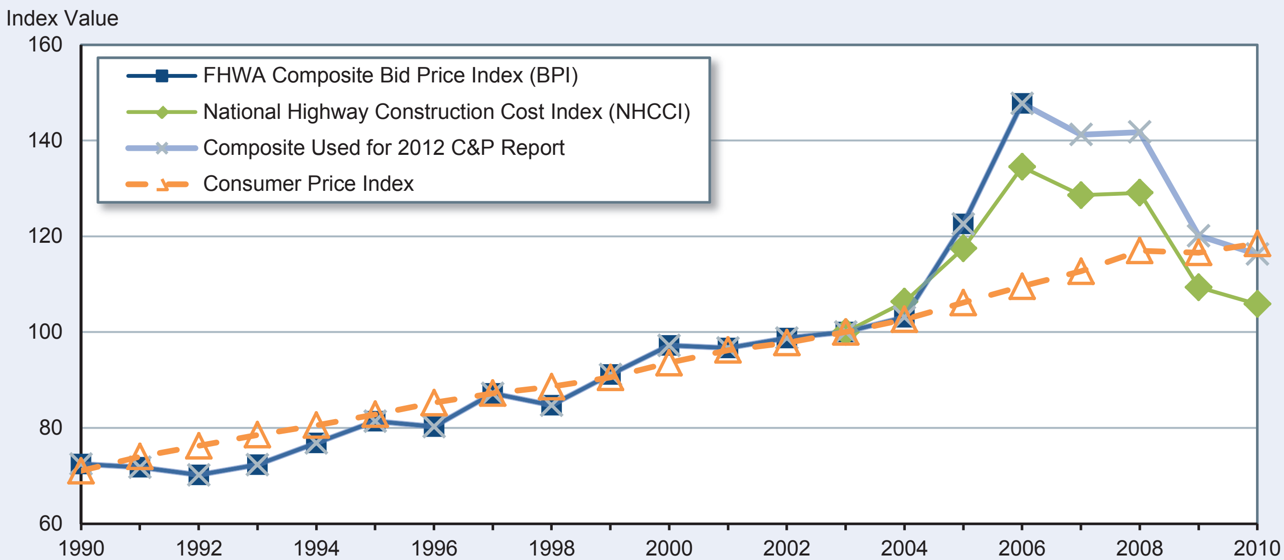
What highway inflation indices are used in this report?

Q&A

There are significant differences in the types of inputs of materials and labor that are associated with different types of highway expenditures; for example, on a dollar-per-dollar basis, highway maintenance activities are generally more labor intensive than highway construction activities. This report uses different indices for converting nominal dollar highway spending to constant dollars for capital and noncapital expenditures. For constant dollar conversions for highway capital expenditures, the Federal Highway Administration (FHWA) Composite Bid Price Index (BPI) is used through the year 2006, the last year for which this index was produced. Capital expenditure conversions for subsequent years rely on a new index, the FHWA National Highway Construction Cost Index (NHCCI). Constant dollar conversions for other types of highway expenditures are based on the Bureau of Labor Statistics' Consumer Price Index (CPI).

Exhibit 6-11 illustrates the trends in cost indices used in the report, converted to a common base year of 2003 (the first year of the NHCCI). Over the 20-year period from 1990 to 2010, the CPI increased by 66.8 percent; in contrast, the combination of the BPI and NHCCI rose by 60.5 percent. Industry-specific indices such as the BPI and NHCCI tend to be more volatile than the CPI, which reflects general trends within the overall economy. This volatility was demonstrated in the period between 2004 and 2006 as sharp increases in the prices of materials such as steel, asphalt, and cement caused the BPI to increase by 43.3 percent, compared with a 6.7 percent increase in the CPI. Since 2006, the NHCCI has decreased by 21.3 percent, so that the purchasing power of each dollar spent in 2010 is significantly higher. This enabled many States to fund more projects under the Recovery Act than they had initially expected.

Exhibit 6-11 Comparison of Inflation Indices (Converted to a 2003 Base Year), 1990–2010



* In order to facilitate comparisons of trends, each index was mathematically converted so that its value for the year 2003 would be equal to100.

Sources: FHWA Highway Statistics, various years, Table PT-1; http://www.bls.gov/cpi/.

Highway Capital Outlay

States provide the FHWA with detailed data on what they spend on arterials and collectors, classifying capital outlay on each functional system into 17 improvement types. Direct State expenditures on arterials and collectors totaled $63.0 billion in 2010, drawing upon a combination of State revenues, transfers from the Federal government, and transfers from local governments. *Exhibit 6-12* illustrates the distribution of these expenditures by improvement type, and how these improvement types have been allocated among three broad categories: system rehabilitation, system expansion, and system enhancement. These broad categories are also used in Chapter 7 to discuss the different components of future capital investment

How are "system rehabilitation," "system expansion," and "system enhancement" defined in this report?

Q&A

System rehabilitation consists of capital improvements on existing roads and bridges that are intended to preserve the existing pavement and bridge infrastructure. These activities include reconstruction, resurfacing, pavement restoration or rehabilitation, widening of narrow lanes or shoulders, bridge replacement, and bridge rehabilitation. Also included is the portion of widening (lane addition) projects estimated to be related to reconstructing or improving existing lanes. System rehabilitation does not include routine maintenance costs.

System expansion includes construction of new roads and new bridges and addition of new lanes to existing roads. This includes all "New Construction," "New Bridge," "Major Widening," and most of the costs associated with "Reconstruction-Added Capacity," except for the portion of these expenditures estimated to be related to improving the existing lanes of a facility.

System enhancement includes safety enhancements, traffic operations improvements such as the installation of intelligent transportation systems, and environmental enhancements.

Exhibit 6-12 **Highway Capital Outlay by Improvement Type, 2010**

	Distribution of Capital Outlay, Billions of Dollars				
		System Expansion			
Type of Expenditure	System Rehabilitation	New Roads and Bridges	Existing Roads	System Enhancements	Total Outlay
Direct State Expenditures on Arterials and Collectors					
Right-of-Way		$1.5	$2.2		**$3.7**
Engineering	$4.7	$0.7	$1.1	$0.7	**$7.2**
New Construction		$4.8			**$4.8**
Relocation			$1.0		**$1.0**
Reconstruction—Added Capacity	$1.7		$4.0		**$5.7**
Reconstruction—No Added Capacity	$3.3				**$3.3**
Major Widening			$3.1		**$3.1**
Minor Widening	$1.3				**$1.3**
Restoration and Rehabilitation	$17.1				**$17.1**
Resurfacing	$0.0				**$0.0**
New Bridge		$0.5			**$0.5**
Bridge Replacement	$5.5				**$5.5**
Major Bridge Rehabilitation	$3.0				**$3.0**
Minor Bridge Work	$2.1				**$2.1**
Safety				$2.1	**$2.1**
Traffic Management/Engineering				$0.9	**$0.9**
Environmental and Other				$1.8	**$1.8**
Total, State Arterials and Collectors	**$38.7**	**$7.5**	**$11.4**	**$5.4**	**$63.0**
Total, Arterials and Collectors, All Jurisdictions (estimated)*					
Highways and Other	$33.8	$8.8	$13.9	$7.0	$63.6
Bridges	$13.1	$0.7			$13.8
Total, Arterials and Collectors	**$46.9**	**$9.5**	**$13.9**	**$7.0**	**$77.4**
Total Capital Outlay on All Systems (estimated)*					
Highways and Other	$42.9	$11.5	$15.0	$12.8	$82.2
Bridges	$17.1	$0.9			$18.0
Total, All Systems	**$60.0**	**$12.4**	**$15.0**	**$12.8**	**$100.2**
Percent of Total	**59.9%**	**12.4%**	**15.0%**	**12.8%**	**100.0%**

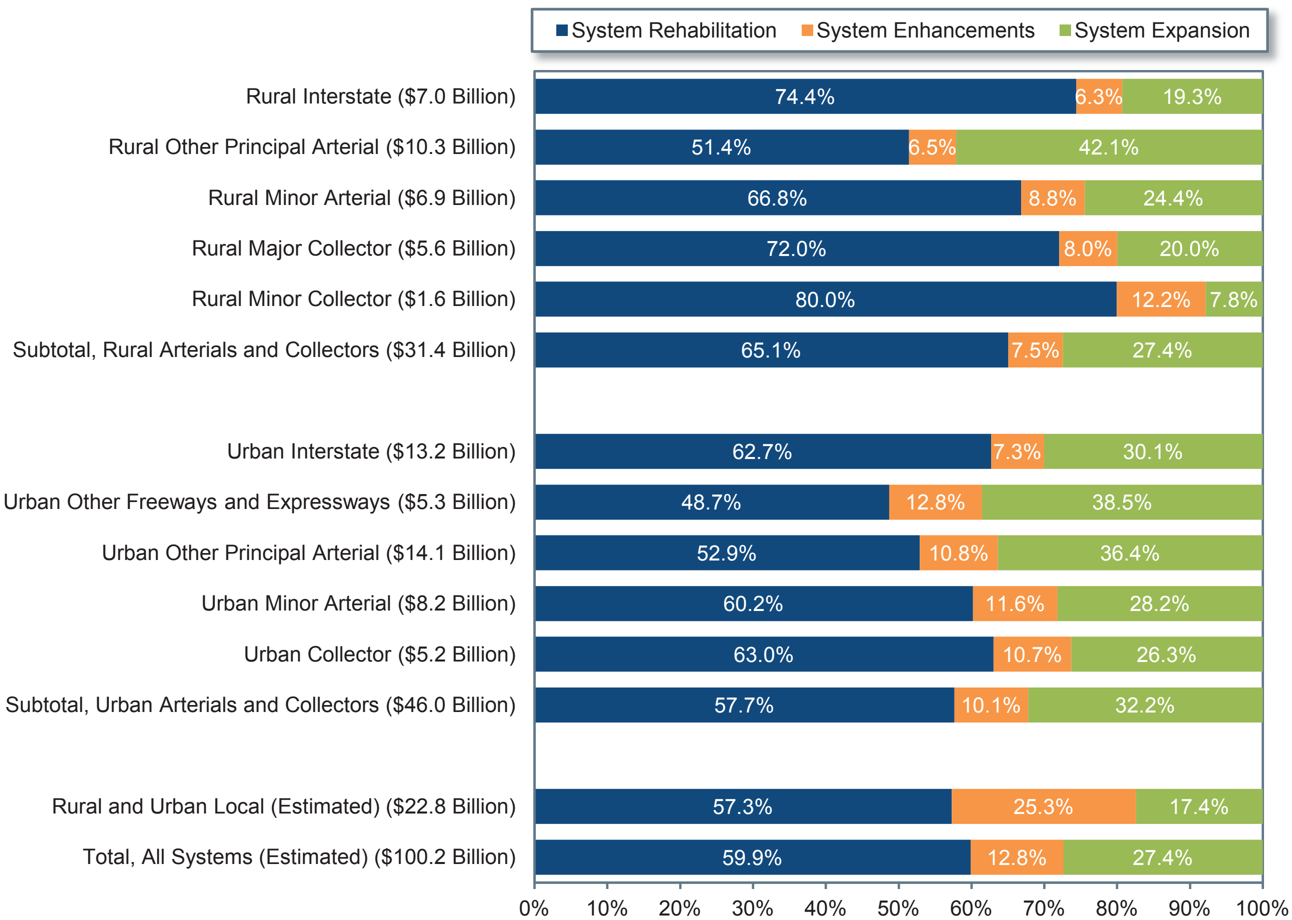
**Improvement type distribution was estimated based on State arterial and collector data.*

Sources: Highway Statistics 2010, Table SF-12A, and unpublished FHWA data.

scenarios. *Exhibit 6-12* presents an estimated distribution of total highway capital outlay by all levels of government on all roads. Of the $100.2 billion in total highway capital outlay, an estimated $60.0 billion was used for system rehabilitation, $27.4 billion went for system expansion, and $12.8 billion was used for system enhancement. These estimates are derived based primarily on State expenditure patterns on arterials and collectors, along with limited data from other sources.

Exhibit 6-13 shows the distribution of capital expenditures by type and functional system. $31.4 billion was invested on rural arterials and collectors in 2010, with 65.1 percent directed towards system rehabilitation and 27.4 percent towards expansion; the remainder was directed toward system enhancement. Capital outlays on urban arterials and collectors were $46.0 billion, of which 57.7 percent went for system rehabilitation and 32.2 percent went for system expansion.

Exhibit 6-13 Distribution of Capital Outlay by Improvement Type and Functional System, 2010



Sources: Highway Statistics 2008, Table SF-12A, and unpublished FHWA data.

Exhibit 6-14, shows trends in capital outlays by improvement type from 2000 to 2010. Each year, a majority of capital outlays were directed towards system rehabilitation reflecting the need to preserve the aging system. However, system preservation's share of total capital spending rose dramatically between 2008 and 2010, rising from 51.1 percent to 59.9 percent. System rehabilitation expenditures increased from $46.2 billion to $60.0 billion, an increase of almost 30 percent over the 2 years. This dramatic increase was partly driven by the Recovery Act. One of the goals of the Recovery Act was to support jobs through

construction expenditures, providing an incentive for the selection of projects that could be initiated and completed relatively quickly. This led many States to direct a larger portion of their Recovery Act funding toward pavement improvement projects than they usually do from regular Federal-aid funds in a typical year. (For example, in 2008, States obligated 42.3 percent to the types of projects that would be classified as "System Rehabilitation-Highway" in this report. However, the share of Recovery Act funding obligated for such projects in 2009 and 2010 was 58.3 percent. This was however, partially offset by a lower share of Recovery Act funding being obligated to the "System Rehabilitation-Bridges" category.)

Exhibit 6-14 Capital Outlay on All Roads by Improvement Type, 2000–2010

Improvement Type	Capital Outlay, Billions of Dollars 2000	2002	2004	2006	2008	2010	Annual Rate of Change 2010/2000
System Rehabilitation							
Highway	$25.0	$25.5	$26.7	$31.0	$33.5	$42.9	5.5%
Bridge	$7.3	$10.7	$9.6	$10.3	$12.7	$17.1	8.9%
Subtotal	**$32.3**	**$36.2**	**$36.3**	**$41.3**	**$46.2**	**$60.0**	**6.4%**
System Expansion							
Additions to Existing Roadways	$11.4	$11.9	$12.1	$14.0	$15.7	$15.0	2.8%
New Routes	$10.5	$11.4	$12.6	$15.2	$16.1	$11.5	0.9%
New Bridges	$1.1	$1.1	$1.4	$1.2	$1.5	$0.9	-2.0%
Subtotal	**$23.0**	**$24.4**	**$26.1**	**$30.4**	**$33.3**	**$27.4**	**1.8%**
System Enhancements	**$6.1**	**$7.6**	**$7.8**	**$8.5**	**$10.9**	**$12.8**	**7.7%**
Total	**$61.3**	**$68.2**	**$70.3**	**$80.2**	**$90.4**	**$100.2**	**5.0%**
Percent of Total Capital Outlay							
System Rehabilitation	52.7%	53.1%	51.7%	51.5%	51.1%	59.9%	
System Expansion	37.4%	35.8%	37.1%	37.9%	36.9%	27.4%	
System Enhancements	9.9%	11.1%	11.2%	10.6%	12.0%	12.8%	

Sources: Highway Statistics 2010, Table SF-12A, and unpublished FHWA data.

Over the 10-year period from 2000 to 2010, system rehabilitation expenditures grew at an average annual rate of 6.4 percent. System expansion expenditures have increased at a slower average annual rate of 1.8 percent, resulting in a decline in share of total capital outlays from 37.4 percent in 2000 to 27.4 percent in 2010. System enhancement expenditures have grown more quickly, rising from 9.9 percent of total capital outlays in 2000 to 12.8 percent in 2010.

How have constant dollar expenditures for different capital improvement types grown in recent years?

Q&A

As noted earlier in this section, total capital outlay by all levels of government grew at an average annual rate of 3.2 percent from 2000 to 2010 in constant dollar terms. Constant dollar system rehabilitation expenditures rose by 4.5 percent per year over this period, while system expansion expenditures showed little annual change. Expenditures for system enhancements grew by 5.8 percent per year in constant dollar terms from 2000 to 2010.

Q&A

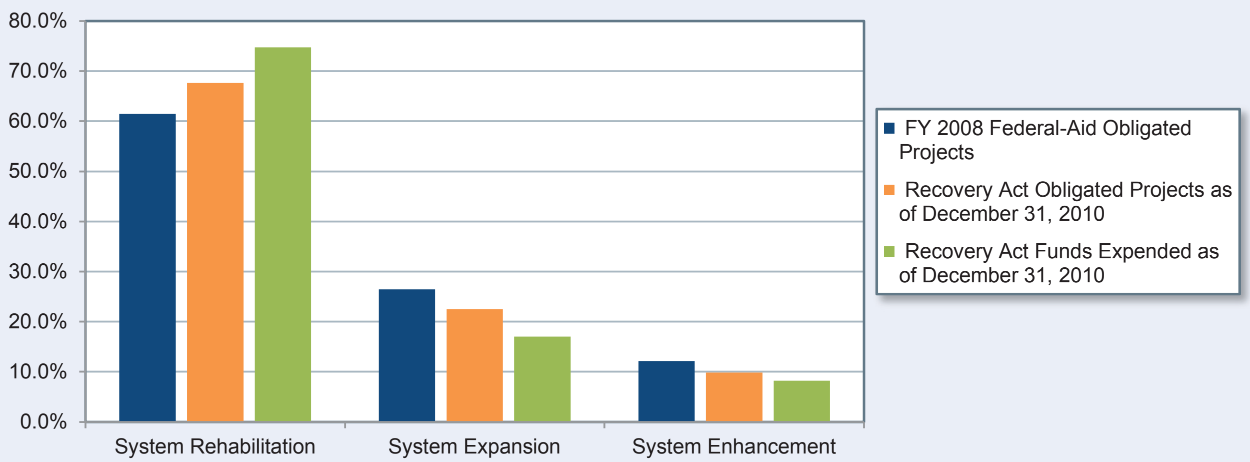
Was the share of recovery funds spent on system rehabilitation higher than the share of 2008 system rehabilitation expenditures?

The spending pattern of the Recovery Act funds has been different from the year 2008 spending. *Exhibit 6-15* presents the 2008 FHWA obligations and Recovery Act obligations and expenditures through December 2010. Rehabilitation expenditures account for more than 50 percent of the obligations for both periods, but under the Recovery Act, the share has increased to above 60 percent in obligations and well over 70 percent in the funds expended through December 2010.

The Recovery Act had specific requirements regarding the time by which the funds had to be obligated. The objectives of the Act were to ensure that funds were quickly invested to support construction jobs lost due to the economic recession. To encourage the States and other funding recipients to select projects quickly, they were required to obligate 50 percent of the Recovery Act funds (excluding sub-allocations to local entities) within 120 days of apportionment or lose funding to other States that were successful in meeting this deadline. All recipients were required to obligate 100 percent of their funds by the end of September 2010 or lose what was remaining. States were requested to select projects that were ready. This resulted in choosing projects that required minimum level of planning and approval. This favored the selection of rehabilitation and replacement projects.

The share of Recovery Act expenditures for system rehabilitation is higher than the share of Recovery Act funds obligated for that purpose (74.7 per cent compared to 67.6 per cent) because rehabilitation and resurfacing projects are likely to incur expenditures sooner than other types of projects. Resurfacing and pavement rehabilitation typically require less advance planning and can be completed in a shorter timeframe. Alternatively, expansion projects require more planning and coordination and may include purchase of right of way, and project construction may range from a few months to multiple years.

Exhibit 6-15 Comparison of FHWA Expenditures by Type, Prior to and During the Recovery Act



Source: FHWA Recovery Act Data.

Capital Outlays on Federal-Aid Highways

As discussed in Chapter 2, the term "Federal-aid Highways" refers to roads that are generally eligible for Federal funding, and excludes roads that are functionally classified as rural minor, rural local or urban local. *Exhibit 6-16* shows that total capital outlays on Federal-aid highways increased at an average annual rate of 4.6 percent from 2000 to 2010, rising to $75.8 billion in 2010.

Capital outlays on system rehabilitation increased from $35.5 billion in 2008 to $45.6 billion in 2010, an increase greater than the increase in total capital outlays on the Federal-aid system. The share of system rehabilitation increased from 50.7 percent in 2008 to 60.2 percent in 2010.

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Exhibit 6-16 Capital Outlay on Federal-Aid Highways, by Improvement Type, 2000–2010

Improvement Type	2000	2002	2004	2006	2008	2010	Annual Rate of Change 2010/2000
	Capital Outlay, Billions of Dollars						
System Rehabilitation							
Highway	$19.3	$19.6	$19.4	$22.9	$26.1	$33.1	5.5%
Bridge	$5.5	$8.3	$7.2	$7.7	$9.3	$12.5	8.6%
Subtotal	**$24.8**	**$27.9**	**$26.6**	**$30.6**	**$35.5**	**$45.6**	**6.3%**
System Expansion							
Additions to Existing Roadways	$10.4	$11.0	$11.6	$12.9	$14.3	$13.8	2.9%
New Routes	$8.4	$9.1	$9.8	$12.0	$12.8	$8.8	0.4%
New Bridges	$0.9	$0.9	$1.2	$0.9	$1.0	$0.7	-2.5%
Subtotal	**$19.7**	**$21.0**	**$22.6**	**$25.9**	**$28.1**	**$23.3**	**1.7%**
System Enhancements	**$3.8**	**$4.8**	**$5.0**	**$5.5**	**$6.4**	**$6.8**	**6.1%**
Total	**$48.3**	**$53.7**	**$54.2**	**$61.9**	**$70.0**	**$75.8**	**4.6%**
Percent of Total Capital Outlay							
System Rehabilitation	51.4%	52.0%	49.1%	49.3%	50.7%	60.2%	
System Expansion	40.8%	39.1%	41.6%	41.9%	40.1%	30.8%	
System Enhancements	7.8%	8.9%	9.3%	8.8%	9.2%	9.0%	

Sources: Highway Statistics 2008, Table SF-12A, and unpublished FHWA data.

Capital Outlays on the National Highway System

The National Highway System (NHS) includes roads important to the Nation's economy, defense and mobility, as described in chapter 2. *Exhibit 6-17* shows that $44.4 billion of capital investments were made on the NHS in 2010, having grown at an average annual rate of 4.0 percent since 2000.

On the NHS, the shift within capital expenditures towards system rehabilitation is even more significant than for all highways and the Federal-aid system. NHS system rehabilitation expenditures increased from $20.4 billion to $27.3 billion, increasing its share of total capital spending from 48.5 percent in 2008 to 61.5 percent in 2010.

Exhibit 6-17 Capital Outlay on the NHS, by Improvement Type, 2000–2010

Improvement Type	2000	2002	2004	2006	2008	2010	Annual Rate of Change 2010/2000
	Capital Outlay, Billions of Dollars						
System Rehabilitation							
Highway	$11.1	$10.6	$9.5	$12.3	$14.9	$19.9	6.0%
Bridge	$3.1	$4.5	$4.0	$4.3	$5.4	$7.4	9.3%
Subtotal	**$14.2**	**$15.1**	**$13.5**	**$16.6**	**$20.4**	**$27.3**	**6.8%**
System Expansion							
Additions to Existing Roadways	$6.4	$7.1	$7.1	$8.1	$9.2	$8.6	3.1%
New Routes	$6.6	$6.7	$6.8	$8.9	$8.6	$4.7	-3.3%
New Bridges	$0.8	$0.6	$0.9	$0.7	$0.6	$0.3	-7.9%
Subtotal	**$13.7**	**$14.5**	**$14.8**	**$17.7**	**$18.3**	**$13.7**	**0.0%**
System Enhancements	**$2.0**	**$2.8**	**$2.8**	**$2.8**	**$3.3**	**$3.4**	**5.6%**
Total	**$29.9**	**$32.4**	**$31.1**	**$37.2**	**$42.0**	**$44.4**	**4.0%**
Percent of Total Capital Outlay							
System Rehabilitation	47.5%	46.7%	43.5%	44.7%	48.5%	61.5%	
System Expansion	46.0%	44.7%	47.6%	47.7%	43.7%	30.9%	
System Enhancements	6.6%	8.7%	8.9%	7.6%	7.8%	7.6%	

Sources: Highway Statistics 2008, Table SF-12B, and unpublished FHWA data.

Capital Outlay on the Enhanced NHS

MAP-21 redefines the NHS to include principal arterial mileage not previously included, as well as connectors to the added principal arterials. In 2010, capital outlay on the NHS totaled $44.4 billion, while capital outlay on principal arterials not on the NHS totaled $8.4 billion. Adding the two produces an estimated capital outlay figure of $53.9 billion.

Capital Outlays on the Interstate System

The Interstate system supports the movement of goods and people across the country. *Exhibit 6-18* shows that the total capital outlay expenditures for 2010 were $20.2 billion, an increase of only $0.2 billion from 2008, a very low growth compared to the historic growth rates. System rehabilitation expenditures increased from $10.8 billion in 2008 to $13.5 billion in 2010, and the system expansion expenditures decreased from $7.8 billion to $5.3 billion, resulting in a system rehabilitation share of 66.7 percent and system expansion of 26.3 percent in 2010.

Exhibit 6-18 **Capital Outlay on the Interstate System, by Improvement Type, 2000–2010**

	Capital Outlay, Billions of Dollars						Annual Rate of Change
Improvement Type	**2000**	**2002**	**2004**	**2006**	**2008**	**2010**	**2010/2000**
System Rehabilitation							
Highway	$5.8	$5.5	$4.7	$5.8	$7.5	$9.4	4.9%
Bridge	$1.6	$2.4	$2.3	$2.5	$3.3	$4.1	9.9%
Subtotal	**$7.4**	**$8.0**	**$7.0**	**$8.3**	**$10.8**	**$13.5**	**6.2%**
System Expansion							
Additions to Existing Roadways	$2.5	$3.2	$2.9	$3.2	$4.5	$3.5	3.6%
New Routes	$2.6	$2.5	$2.5	$3.5	$3.0	$1.7	-4.3%
New Bridges	$0.4	$0.2	$0.2	$0.3	$0.3	$0.1	-9.4%
Subtotal	**$5.5**	**$5.9**	**$5.6**	**$7.1**	**$7.8**	**$5.3**	**-0.3%**
System Enhancements	**$0.9**	**$1.4**	**$1.1**	**$1.2**	**$1.4**	**$1.4**	**4.2%**
Total	**$13.8**	**$15.3**	**$13.7**	**$16.5**	**$20.0**	**$20.2**	**3.9%**
Percent of Total Capital Outlay							
System Rehabilitation	53.7%	52.1%	50.8%	49.9%	53.9%	66.7%	
System Expansion	39.6%	38.5%	40.9%	42.6%	38.9%	26.3%	
System Enhancements	6.7%	9.4%	8.3%	7.4%	7.1%	6.9%	

Sources: Highway Statistics 2008, Table SF-12A, and unpublished FHWA data.

Innovative Finance

In recent years, State and Local transportation agencies have adopted new ways of financing and delivering transportation projects. In the face of stagnating public revenues and demanding fiscal requirements, many jurisdictions are utilizing innovative options such as public-private partnerships, Federal credit assistance, and other debt financing tools. These strategies may enable financially strapped public agencies to deliver costly and complex infrastructure projects much earlier than would be possible through traditional mechanisms.

Public-Private Partnerships

Public-Private Partnerships (P3s) are contractual agreements formed between a public agency and a private entity that allow for greater private sector participation in the delivery and financing of transportation projects. Typically, this participation involves the private sector taking on additional project risks, such as design, finance, long-term operation, maintenance, or traffic revenue. P3s are undertaken for a variety of purposes, including monetizing the value of existing assets, developing new transportation facilities, or rehabilitating or expanding existing facilities. While P3s may offer certain advantages, such as increased financing capacity and reducing up-front costs, the public sector still must identify a source of revenue for the project to provide a return to the private partner's investment, and must ensure that the goals and interests of the public are adequately secured.

Additional information on P3s is available at http://www.fhwa.dot.gov/ipd/p3/index.htm.

Public-Private Partnership Project: IH-635 Managed Lanes (LBJ Express)

The LBJ Express Project will relieve congestion north of Dallas on 13 miles of IH-635 (LBJ Freeway) from just west of IH-35E to just east of US-75, and south on IH-35E from I-635 to Loop 12. The project will involve:

- Reconstruction of the main lanes and frontage roads along IH-635
- Addition of six managed lanes (mostly subsurface) along IH-635 from IH-35E to US-75 and four managed lanes west and east of that stretch
- Addition of six elevated managed lanes along IH-35E from Loop 12 to the IH-35E/IH-635 interchange.

The project is being built under a public-private partnership (Comprehensive Development Agreement) executed in September 2009 between the Texas Department of Transportation and LBJ Infrastructure Group, which will operate and maintain the facility for 52 years. Construction began in early 2011 and is expected to be complete by December 2015. The total cost of the project is $2.6 billion.

Federal Credit Assistance

Federal credit assistance for highway improvements can take one of two forms: loans, where project sponsors borrow Federal highway funds directly from a State DOT or the Federal government; and credit enhancements, where a State DOT or the Federal government makes Federal funds available on a contingent (or standby) basis. Credit enhancement helps reduce risk to investors and thus allows project sponsors to borrow at lower interest rates. Loans can provide the capital necessary to proceed with a project, and reduce the amount of capital borrowed from other sources, and may also serve a credit enhancement function by reducing the risk borne by other investors. Federal tools currently available to project sponsors include the Transportation Infrastructure and Finance Innovation Act (TIFIA) program, State Infrastructure Bank (SIB) programs, and Section 129 loans.

The TIFIA Credit Program provides Federal credit assistance in the form of direct loans, loan guarantees, and standby lines of credit to finance surface transportation projects of national and regional significance. A TIFIA project must pledge repayment in whole or in part with dedicated revenue sources such as tolls, user fees, special assessments (taxes), or other non-Federal sources. SIBs are State-run revolving funds that provide loans, credit enhancements, and other forms of non-grant assistance to surface transportation projects. SIBs can be capitalized with regularly apportioned Federal-aid funds. Section 129 loans allow States to lend apportioned Federal-aid highway funds to toll and non-toll projects generating dedicated revenue streams.

Additional information on credit assistance tools is available at http://www.fhwa.dot.gov/ipd/finance/tools_programs/federal_credit_assistance/index.htm

Federal Credit Assistance Project – Port of Miami Tunnel

The Port of Miami Tunnel will improve access to and from the Port of Miami, serving as a dedicated roadway connector linking the port (located on an island in Biscayne Bay) with the MacArthur Causeway and I-395 on the mainland. Currently, the Port is linked to the mainland only by the Port Bridge. The project includes a tunnel under the Main Channel (the shipping channel between Dodge and Watson Islands), roadway work on Dodge Island and Watson Island/MacArthur Causeway, and widening the MacArthur Causeway Bridge. Twin tubes, each 3,900 feet long and 41 feet in diameter, will reach a depth of 120 feet below the water.

The project is being developed and operated as a public-private partnership with Miami Access Tunnel, LLC (MAT). Under the concession agreement, the Florida DOT will provide MAT with milestone payments during the construction period (2010–2014) and a final acceptance payment upon construction completion in 2014. This will be followed by 30 years of availability payments during the operating period. Deductions will be made from this amount if MAT's operation of the facility does not meet prescribed performance standards. The State has agreed to pay for approximately 50 percent of the capital costs (design and construction) and all operations and maintenance, while the remaining 50 percent of the capital costs will be provided by Miami-Dade County and the City of Miami.

Financing for this $1.1 billion project includes a $341 million TIFIA loan secured by a pledge of the availability payments due to the concessionaire. The TIFIA loan was executed in October 2009.

Debt Financing Tools

Some transportation projects are so large that their cost exceeds available current grant funding and tax receipts or would consume so much of these current funding sources as to delay many other planned projects. For this reason, State and local governments often look to finance large projects through borrowing, which provides an immediate influx of cash to fund project construction costs. The borrower then retires the debt by making principal and interest payments over time. Tax-exempt municipal bonds, backed by future government revenues, are the most common method of borrowing by government agencies for transportation projects.

Three innovative debt instrument tools—Grant Anticipation Revenue Vehicles (GARVEEs), Private Activity Bonds (PABs), and Build America Bonds (BABs)—provide further borrowing opportunities. A GARVEE is a debt financing instrument—such as a bond, note, certificate, mortgage, lease, or other debt financing technique—that has a pledge of future Federal-aid funding. PABs are debt instruments issued by State or local governments on behalf of a private entity for highway and freight transfer projects, allowing a private project sponsor to benefit from the lower financing costs of tax-exempt municipal bonds. BABs, which were authorized by the American Recovery and Reinvestment Act (Recovery Act), are taxable bonds that are eligible for an interest rate subsidy paid directly from the U.S. Treasury. The Recovery Act allowed States and local governments to issue BABs through December 2010.

Additional information on Federal debt financing tools is available at http://www.fhwa.dot.gov/ipd/finance/tools_programs/federal_debt_financing/index.htm.

Debt Financing Tool Project: Maine's Veterans Memorial Bridge

Maine's third Grant Anticipation Revenue Vehicles (GARVEE) sale took place in November 2010 in the amount of $50 million in Taxable Build America Bonds issued by the Maine Municipal Bond Bank. A portion of the proceeds is being used to partially fund the construction of the replacement of the Veterans Memorial Bridge over the Fore River between the Cities of Portland and South Portland. The bridge is nearing 60 years of age and is designed to be a gateway to Maine's largest city.

Transit Finance

Transit funding comes from two major sources: public funds allocated by Federal, State, and local governments, and system-generated revenues earned from the provision of transit services. As shown in *Exhibit 6-19*, the total amount available for transit financing in 2010 was $54.3 billion. Federal funding for transit includes fuel taxes dedicated to transit from the Mass Transit Account (MTA) of the Highway Trust Fund (HTF), as well as undedicated taxes allocated from Federal general fund appropriations. State and local governments also provide funding for transit from their General Fund appropriations, as well as from fuel, income, sales, property, and other unspecified taxes, specific percentages of which may be dedicated to transit. These percentages vary considerably among taxing jurisdictions and by type of tax. Other public funds from sources such as toll revenues and general transportation funds may also be used to fund transit. System-generated revenues are composed principally of passenger fares, although additional revenues are also earned by transit systems from advertising and concessions, park-and-ride lots, investment income, and rental of excess property and equipment.

Exhibit 6-19 2010 Revenue Sources for Transit Funding

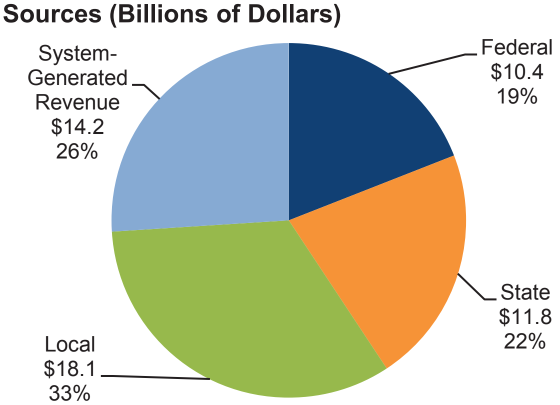
	(Millions of Dollars)				
	Federal	**State**	**Local**	**Total**	**Percent**
Public Funds	**10,364.1**	**11,788.4**	**18,021.1**	**40,173.6**	**73.9%**
General Fund	2,072.8	3,041.0	3,955.3	9,069.1	16.7%
Fuel Tax	8,291.3	587.0	183.4	9,061.7	16.7%
Income Tax		478.7	78.6	557.3	1.0%
Sales Tax		3,140.6	4,556.9	7,697.5	14.2%
Property Tax		27.4	418.1	445.4	0.8%
Other Dedicated Taxes		2,328.0	294.1	2,622.1	4.8%
Other Public Funds		2,185.7	8,534.8	10,720.5	19.7%
System-Generated Revenue				**14,156.2**	**26.1%**
Passenger Fares				12,126.3	22.3%
Other Revenue				2,029.9	3.7%
Total All Sources				**54,329.8**	**100.0%**

Source: National Transit Database.

Level and Composition of Transit Funding

Exhibit 6-20 breaks down the sources of total transit funding. In 2010, public funds of $40.2 billion were available for transit and accounted for 73.9 percent of total transit funding. Of this amount, Federal funding was $10.4 billion, accounting for 25.8 percent of total public funding and for 19.1 percent of all funding from both public and nonpublic sources. State funding was $11.8 billion, accounting for 29.3 percent of total public funds and 21.7 percent of all funding. Local jurisdictions provided the bulk of transit funds, $18 billion in 2010, or 44.9 percent of total public funds and 33.2 percent of all funding. System-generated revenues were $14.2 billion, 26.1 percent of all funding. During the Recovery Act years of 2009, 2010, and 2011, transit agencies reported annual

Exhibit 6-20 2010 Public Transit Revenue Sources (Billions of Dollars)



Source: National Transit Database.

What type of dedicated funding does public transit receive from Federal highway-user fees?

Q&A

In 1983, the MTA was established within the HTF. It is funded by 2.86 cents of Federal highway-user fees on gasohol, diesel and kerosene fuel, and other special fuels (benzol, benzene, and naphtha). Since 1997, the Federal fuel tax on a gallon of gasoline has been 18.4 cents and the tax on a gallon of diesel has been 24.4 cents.

The MTA also receives 2.13 cents of the user fee on liquefied petroleum gas (LPG) and 1.86 cents of the user fee on liquefied natural gas (LNG). The MTA does not receive any of the nonfuel revenues (such as heavy vehicle use taxes) that accrue to the HTF.

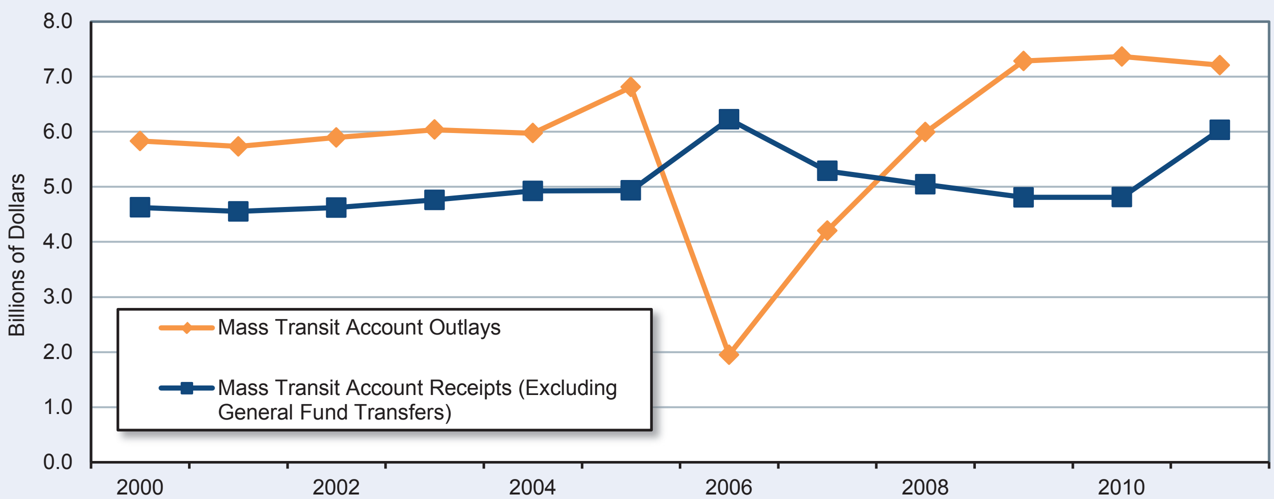
Since the passage of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), only the Formula and Bus Grants Program is funded from the MTA. Prior to SAFETEA-LU, MTA funded other FTA programs.

How long has it been since excise tax revenue deposited into the MTA exceeded expenditures?

Q&A

The last time that annual net receipts credited to the MTA of the HTF exceeded annual expenditures from the Highway Account was in 2007. As shown in *Exhibit 6-21,* for 10 of the 12 years since 2000, total annual receipts to the MTA from excise taxes and other income (including amounts transferred from the Highway Account) have been lower than the annual expenditures from the MTA.

Exhibit 6-21 Mass Transit Account Receipts and Outlays, Fiscal Years 2000–2011



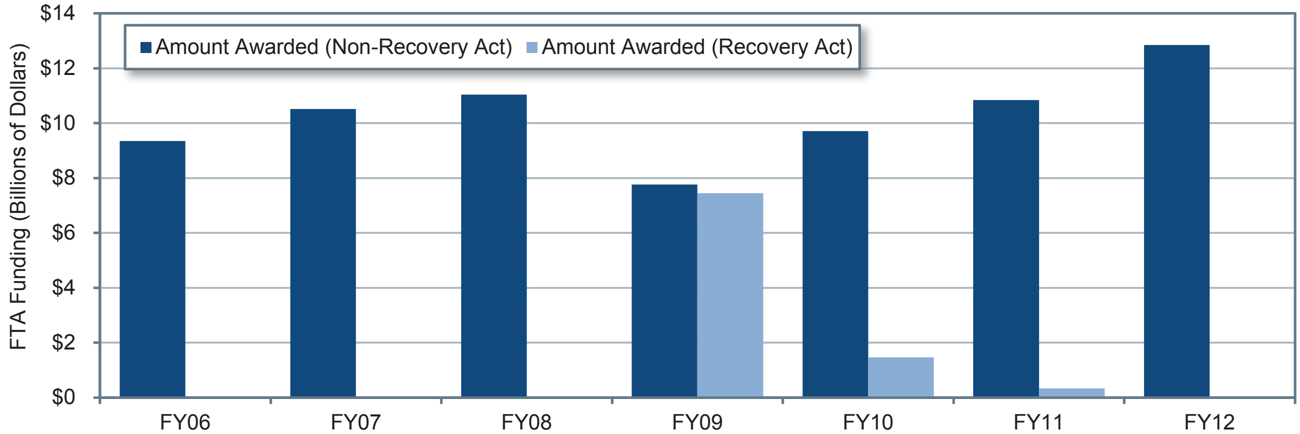
Sources: Highway Statistics, various years, Tables FE-210 and FE-10.

expenditures averaging $17.0 billion. The infusion of $5.3 billion in Recovery Act funds during that period allowed the industry to maintain investment levels near the record 2008 funding level of $17.1 billion.

Federal Funding

Federal funding for transit comes from two sources: the general revenues of the U.S. government and revenues generated from fuel taxes credited to the HTF's MTA. General revenue sources include income taxes, corporate taxes, tariffs, fees, and other government income not required by statute to be accounted for in a separate fund. The MTA, a trust fund for capital projects in transit, is generally the largest source of Federal funding for transit, though it was overtaken by American Recovery and Reinvestment Act (Recovery Act) funds from the general account in 2009. *Exhibit 6-22* shows how Recovery Act funds were awarded in 2009, 2010, and 2011 in comparison to other Federal funding that comes from both the MTA

Exhibit 6-22 Recovery Act Funding Awards Compared to Other FTA Fund Awards



Source: Federal Transit Administration, Grants Data.

and the General Fund. Of the funds authorized for transit grants in FTA's 2010 budget, 79.0 percent were derived from the MTA. Funding from the MTA in nominal dollars increased from $0.5 billion in 1983 to $8.3 billion in 2010.

The Department of Homeland Security (DHS) provides funding for projects aimed at improving transit security. In 2010, DHS provided a total of $253 million to transit service providers.

Since 1973, Federal surface transportation authorization statutes have contained flexible funding provisions that enable transfers from certain highway funds to transit programs and vice versa. Transfers are subject to State and regional/local discretion, and priorities are established through statewide transportation planning processes. All States within the United States participate in the flexible funding program except Arkansas, Delaware, Hawaii, Nebraska, North Dakota, South Dakota, and Wyoming. U.S. territories, including American Samoa, Guam, North Mariana Islands, Puerto Rico, and the Virgin Islands do not participate. Flexible funding transferred from highways to transit fluctuates from year to year and is drawn from several different sources.

The Surface Transportation Program is also the source of Federal Highway Administration (FHWA) funds that are "flexed" to FTA to pay for transit projects. Funding is at 80 percent of Federal share and may be used for all capital and maintenance projects eligible for funds under current Federal Transit Administration

What are Flex Funds?

Q&A

In FY 2008, $1.4 billion in flexible funds/transfers from Federal highway programs were available to FTA for obligation. Of that total, $957.3 million (67.0 percent) was transferred in FY 2008; the remaining available $472.5 million (33.0 percent) was the un-obligated carryover or recovery of prior year transfers. Thirty-nine states transferred flexible funds during FY 2008 and obligations totaled $1.1 billion. Once transferred, these funds take on the characteristics of the program in which they are received and are included in the figures reported across various programs. Obligations in FY 2008 were:

- Urbanized Area Formula: $938.6 million (87.4 percent);
- Capital: $45.6 million (4.2 percent);
- Elderly and Persons with Disabilities: $67.8 million (6.3 percent); and
- Non-urbanized Area Formula: $21.9 million (2.0 percent).

Since the program's initiation in FY 1992, a total of $15.0 billion has been transferred from FHWA for transit projects. FHWA funds can be used for transit projects without being "flexed" to FTA, so this number may understate the total use of highway funds for transit projects.

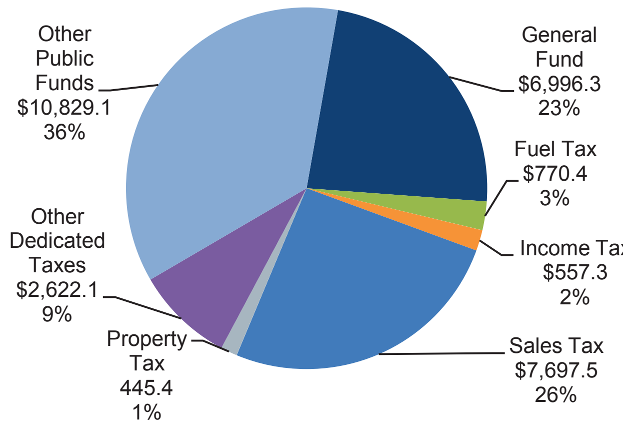
(FTA) programs, and may not be used for operating assistance. FHWA has requested that they be administered by FTA.

FHWA's Congestion Mitigation and Air Quality (CMAQ) Improvement Program funds are another source of flexed funds used to support transit projects in air quality nonattainment areas. A CMAQ project must contribute to the attainment of the national ambient air quality standards by reducing air pollutant emissions from transportation sources. Public transportation projects can be funded through CMAQ, including some provisions for transit operating assistance.

State and Local Funding

General funds and other dedicated public funds (vehicle licensing and registration fees, communications access fees, surcharges and taxes, lottery and casino receipts, and the proceeds from property and asset sales) are important sources of funding for transit at both the State and local levels. State and local funding sources for transit are shown in *Exhibit 6-23*. Taxes, including fuel, sales, income, property and other dedicated taxes, provide 41 percent of total public funds for State and local sources. General Funds provide 23 percent of transit funding with Other Public Funds providing the remaining 36 percent.

Exhibit 6-23 State and Local Sources of Transit Funding (Millions of Dollars)



Source: National Transit Database.

System-Generated Funds

In 2010, system-generated funds were $14.2 billion and provided 26 percent of total transit funding. Passenger fares contributed $12.1 billion, accounting for 22.3 percent of total transit funds. These passenger fare figures do not include payments by State entities to transit systems that offset reduced transit fares for certain segments of the population, such as students and the elderly. These payments are included in the "other revenue" category.

Exhibit 6-24 shows average fares and costs, on a per-mile basis, for the Nation's 10 largest transit agencies since 2000. After adjusting for inflation (constant dollars) there has been a 10 percent increase in fares per mile over this period while the average cost per mile has increased by 19 percent. This has resulted in

Exhibit 6-24 Average Fares and Costs per Mile—Top 10 Transit Systems, 2000–2010 (Constant Dollars)

												% Increase	
Top 10 Systems*	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2000–2010	Average Annual
Average Fare per Mile	$3.61	$3.61	$3.44	$3.37	$3.50	$3.53	$3.64	$3.69	$3.82	$3.82	$3.99	10%	1.0%
Average Cost per Mile	$9.05	$9.21	$9.13	$9.21	$9.34	$9.53	$9.70	$10.10	$10.28	$10.50	$10.82	19%	1.8%
Average Recovery Ratio	39.9%	39.2%	37.7%	36.6%	37.5%	37.0%	37.5%	36.5%	37.2%	36.4%	36.9%	-8%	-0.8%

**MTA New York City, Chicago Transit Authority, Los Angeles County Metropolitan Transportation Authority, Washington Metropolitan Area Transit Authority, Massachusetts Bay Transportation Authority, Southeastern Pennsylvania Transportation Authority, New Jersey Transit Corporation, San Francisco Municipal Railway, Metropolitan Atlanta Rapid Transit Authority, and Maryland Transit Administration.*

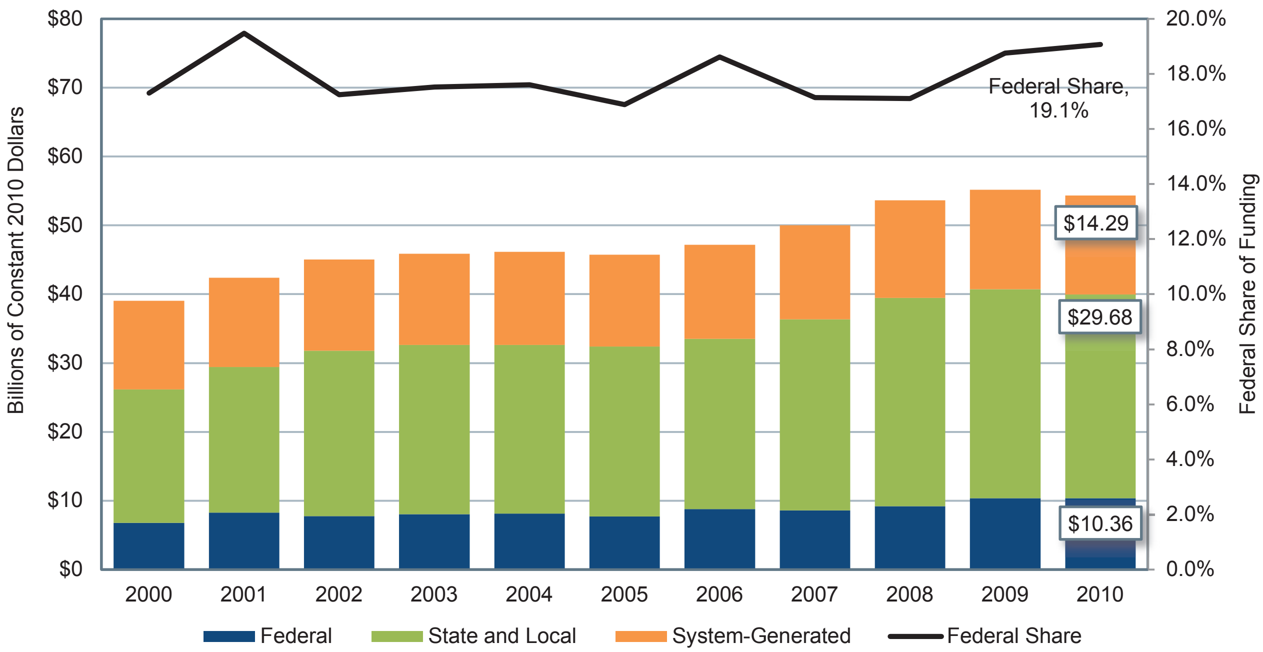
Source: National Transit Database.

an 8.0 percent decrease in the "fare recovery ratio," which is the percentage of operating costs covered by passenger fares. The 2010 fare recovery ratio for these ten agencies was 36.9 percent. Because these are all rail agencies, and rail systems tend to have lower operating costs per passenger mile, this is a higher fare recovery ratio than would be found for most bus or demand response operations. In many cases, municipalities operating these systems have determined that it is more cost effective for them to provide free service as fare collection is expensive and fares for these operations are generally kept low.

Trends in Funding

Between 2000 and 2010, public funding for transit increased at an average annual rate of 4.3 percent, Federal funding increased at an average annual rate of 4.4 percent, and State and local funding grew at an average annual rate of 4.3 percent after adjusting for inflation (constant dollars). These data are presented in *Exhibit 6-25*.

Exhibit 6-25 **Funding for Transit by Government Jurisdiction, 2000–2010**



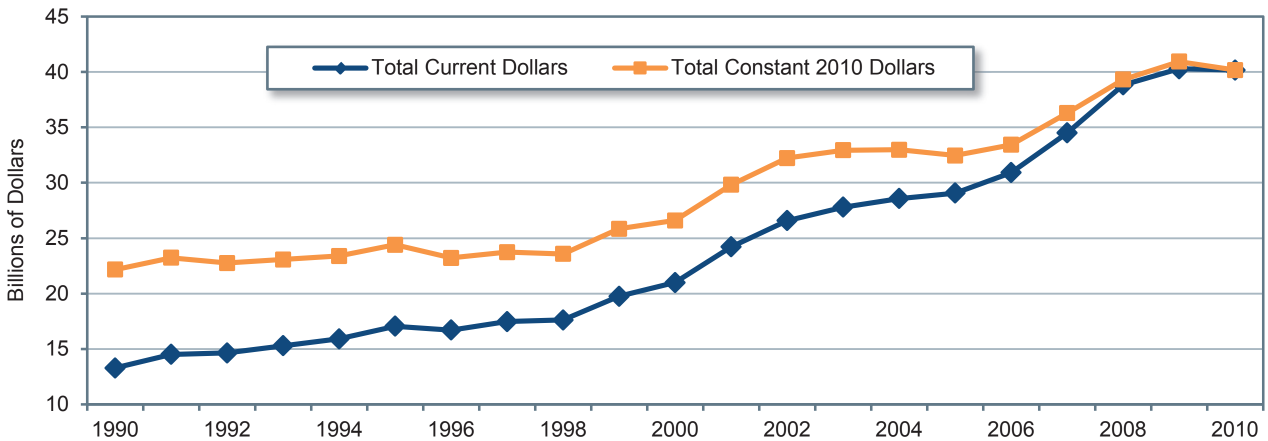
Source: National Transit Database.

Federal funding for transit, as a percentage of total funding for transit from Federal, State, and local sources combined, reached a peak of 42.9 percent in the late 1970s, and declined to near its present value by the early 1990s as State and local funding increased. *Exhibit 6-25* shows that, since 2000, the Federal government has provided between 16.9 and 19.5 percent of total funding for transit (including system-generated funds); in 2010, it provided 19.1 percent of these funds.

Funding in Current and Constant Dollars

Public funding for transit in current and constant dollar terms since 1990 is presented in *Exhibit 6-26*. Total public funding for transit was $40.2 billion in 2010. After adjusting for inflation (constant dollars), this was 2.2 percent higher than in 2008. Between 2008 and 2010 Federal funding increased from nearly $9.0 billion to $10.4 billion (15.3 percent) in current dollars. In constant dollars this represents a 13.9 percent increase. From 2008 to 2010, in current dollars, State and local funding stayed the same at $29.8 billion. In constant dollars this represents a 1.4 percent decrease in funding.

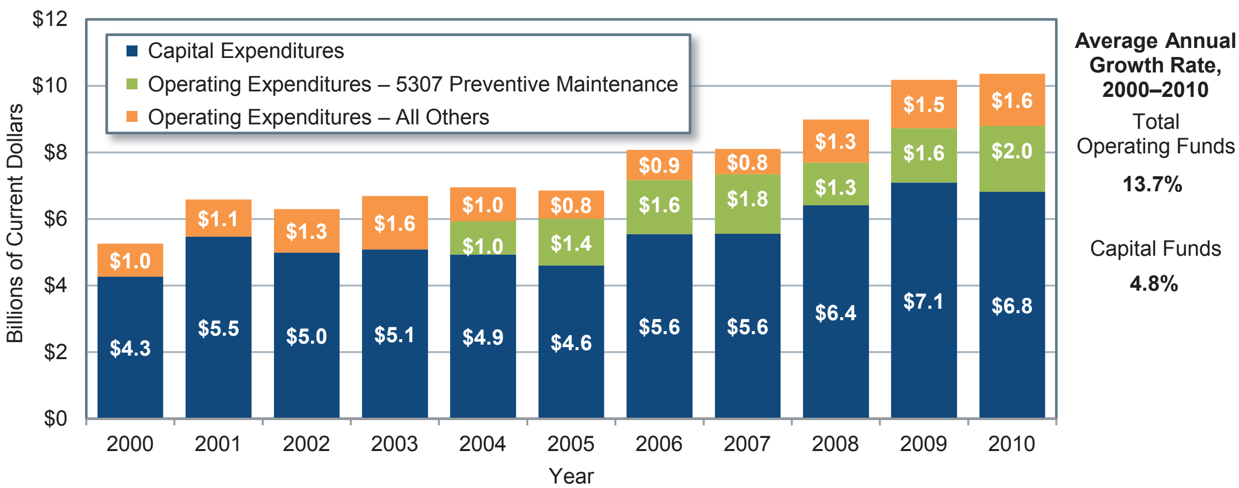
Exhibit 6-26 Current and Constant Dollar Funding for Public Transportation (All Sources)



Source: National Transit Database.

While Federal funds directed to capital expenditures have increased 4.8 percent from 2000 to 2010, funds applied to operating expenditures have increased 13.7 percent during the same period (current dollars). As indicated in *Exhibit 6-27*, $3.6 billion was applied to operating expenditures and $6.8 billion was applied to capital expenditures in 2010. More than half of the operating expenditures were for preventive maintenance, which is reimbursed as a capital expense under FTA's 5307 grant program.

Exhibit 6-27 Applications of Federal Funds for Transit Operating and Capital Expenditures, 2000–2010



Source: National Transit Database.

Capital Funding and Expenditures

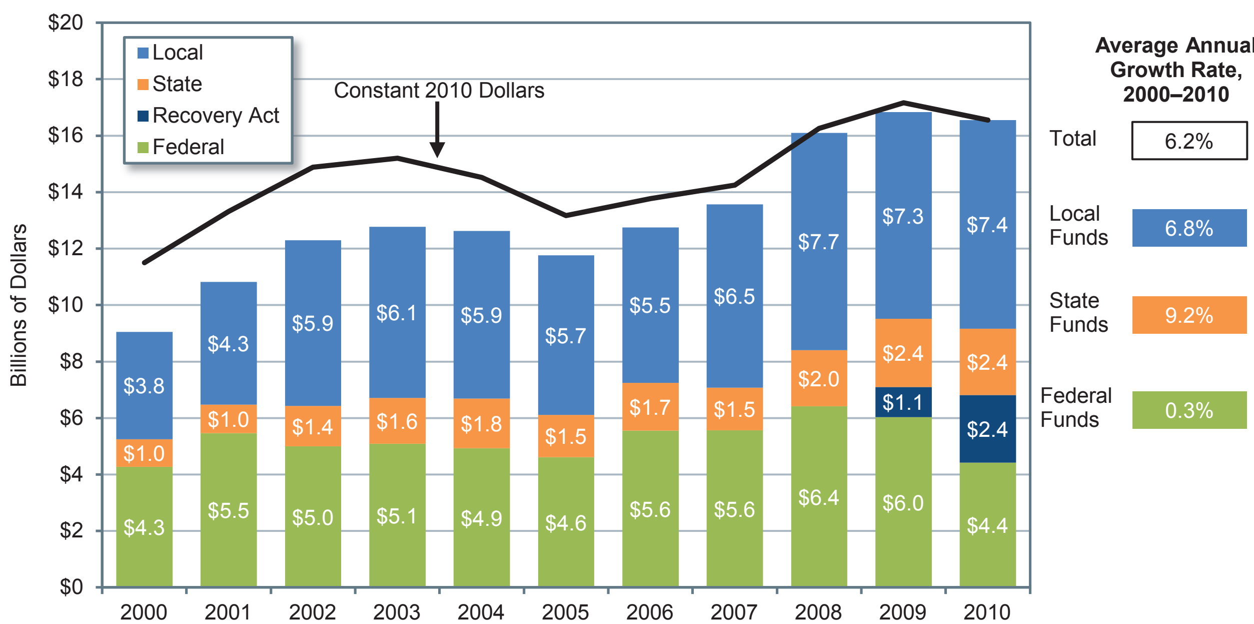
Funding for capital investments by transit operators in the United States comes primarily from public sources. A relatively small amount of private sector funds for capital investment in transit projects are generated through innovative finance programs.

Capital investments include the design and construction of new transit systems, extensions of existing systems ("New Starts"), and the modernization or replacement of existing assets. Capital investment expenditures can be for the acquisition, renovation, and repair of rolling stock (i.e., buses, railcars, locomotives, and service vehicles) or fixed assets (which include fixed guideway systems, terminals, and stations, as well as maintenance and administrative facilities).

As shown in *Exhibit 6-28*, in 2010, total public transit agency expenditures for capital investment were $16.6 billion. This accounted for 41.3 percent of total available funds. Federal funds were $4.4 billion in 2010, 26.6 percent of total transit agency capital expenditures. State funds provided 14.2 percent and local funds provided 44.6 percent of total transit funding. Recovery Act funds provided the remaining 14.5 percent of revenues for agency capital expenditures.

Substantial amounts of Recovery Act funding were made available in 2009 and 2010, years in which use of non-Recovery Act Federal funds for capital investment went down. Total Federal expenditures were only slightly higher than in previous years, so it appears that Recovery Act funds displaced regular FTA grant funds in 2009 and 2010. This is not surprising given the strict 2-year obligation limit specified for Recovery Act funds. They would have to be used first due to their shorter availability period. As transit agencies have limited staff to process grants, and limited "shovel-ready" projects available for funding, expenditure of non-Recovery Act FTA grant funds was delayed so Recovery Act funds could be processed quickly.

Exhibit 6-28 Sources of Funds (Billions of Dollars) for Transit Capital Expenditures, 2000–2010



Source: National Transit Database.

As shown in *Exhibit 6-29*, rail modes require a higher percentage of total transit capital investment than bus modes because of the higher cost of building fixed guideways and rail stations, and because bus systems typically do not pay to build or maintain the roads on which they run. In 2010, $11.9 billion, or 72 percent of total transit capital expenditures, were invested in rail modes of transportation, compared with $4.6 billion, or 28 percent of the total, which was invested in nonrail modes. This investment distribution has been consistent over the last decade.

Fluctuations in the levels of capital investment in different types of transit assets reflect normal rehabilitation and replacement cycles, as well as new investment. Capital investment expenditures have only been reported to the National Transit Database (NTD) at the level of detail in *Exhibit 6-29* since 2002.

Total guideway investment was $6.2 billion in 2010, and total investment in systems was $1.1 billion. Guideway includes at-grade rail, elevated and subway structures, tunnels, bridges, track and power systems for all rail modes, and paved highway lanes dedicated to buses. Investment in systems by transit operators includes groups of devices or objects forming a network, most notably for train control, signaling, and communications.

Exhibit 6-29 2010 Transit Capital Expenditures by Mode and Type

Type	Commuter Rail	Heavy Rail	Light Rail	Other Rail[1]	Total Rail
	Rail Capital Expenditures, Millions of Dollars				
Guideway	$1,812	$2,005	$2,273	$5.5	**$6,096**
Rolling Stock	$403	$877	$327	$3.4	**$1,611**
Systems	$118	$591	$139	$7.7	**$855**
Maintenance Facilities	$159	$84	$92	$1.2	**$337**
Stations	$427	$1,572	$341	$1.7	**$2,342**
Fare Revenue Collection Equipment	$14	$41	$27	$0	**$82**
Administrative Buildings	$5	$30	$7.9	$0.3	**$43**
Other Vehicles	$14	$28	$6.1	$0.1	**$49**
Other Capital Expenditures[2]	$74	$419	$21	$0.6	**$514**
Total	**$3,026**	**$5,646**	**$3,234**	**$20**	**$11,927**
Percent of Total	18.3%	34.1%	19.5%	0.1%	72.0%

Type	Fixed Route Bus	Demand Response	Ferryboat	Vanpool	Total Nonrail
	Nonrail Capital Expenditures, Millions of Dollars				
Guideway	$136	$0	$0	$0	**$136**
Rolling Stock	$2,374	$222	$128	$12	**$2,736**
Systems	$239	$22	$0.20	$0.07	**$261**
Maintenance Facilities	$534	$26	$9.8	$0.01	**$569**
Stations	$379	$0.9	$45.2	$0.01	**$425**
Fare Revenue Collection Equipment	$88	$3.9	$0.24	$0	**$92**
Administrative Buildings	$184	$14	$7.2	$0.16	**$206**
Other Vehicles	$35	$1.2	$0	$0.02	**$36**
Other Capital Expenditures[2]	$156	$7.0	$11.9	$0.32	**$176**
Total	**$4,125**	**$297**	**$203**	**$12**	**$4,637**
Percent of Total	24.9%	1.8%	1.2%	0.1%	28.0%

Type	Total Expenditures, Millions of Dollars for Rail and Nonrail Modes	Percent of Total
Guideway	**$6,232**	37.6%
Rolling Stock	**$4,347**	26.2%
Systems	**$1,117**	6.7%
Maintenance Facilities	**$906**	5.5%
Stations	**$2,766**	16.7%
Fare Revenue Collection Equipment	**$174**	1.1%
Administrative Buildings	**$249**	1.5%
Other Vehicles	**$85**	0.5%
Other Capital Expenditures[2]	**$689**	4.2%
Total	**$16,564**	**100.0%**

[1] Alaska railroad, automated guideway, cable car, inclined plane, and monorail.

[2] Capital expenditures not elsewhere included. These expenditures include furniture and equipment that are not an integral part of buildings and structures; they also include shelters, signs, and passenger amenities (e.g., benches) not in passenger stations.

Note: Fixed Route Bus includes Motor Bus and Trolleybus.

Source: National Transit Database.

Total investment in rolling stock in 2010 was $4.3 billion, total investment in stations was $2.8 billion, and total investment in maintenance facilities was $0.9 billion. Rolling stock includes the bodies and chassis of transit vehicles and their attached fixtures and appliances, but does not include fare collection equipment and revenue vehicle movement control equipment such as radios. Stations include station buildings, platforms, shelters, parking and other forms of access, and crime prevention and security equipment at stations. Facilities include the purchase, construction, and rehabilitation of administrative and maintenance

What are "New Starts?"

FTA provides dedicated funding for the construction of new fixed guideway systems through a competitive program known as "New Starts". Title 49 USC Section 5309 provides for the allocation of funds for the design and construction of new transit systems and extensions to current systems ("New Starts"), among other purposes. To receive FTA capital investment funds for a New Starts project, the proposed project must emerge from the metropolitan and/or statewide planning process. A rigorous series of planning and project development requirements must be completed in order for a project to qualify for this funding. FTA evaluates proposed projects on the basis of financial criteria and project justification criteria as prescribed by statute. Initial planning efforts are not funded through the Section 5309 program, but may be funded through Section 5303, Metropolitan Planning; Section 5339, Alternatives Analysis; or Section 5307, Urbanized Area Formula Grants programs.

Under current law, Federal funding may account for up to 80 percent of a New Starts funding requirement. Generally, the Federal share of such projects now averages about 50 percent of the total project cost. However, not all new fixed guideway projects are constructed through the New Starts Program.

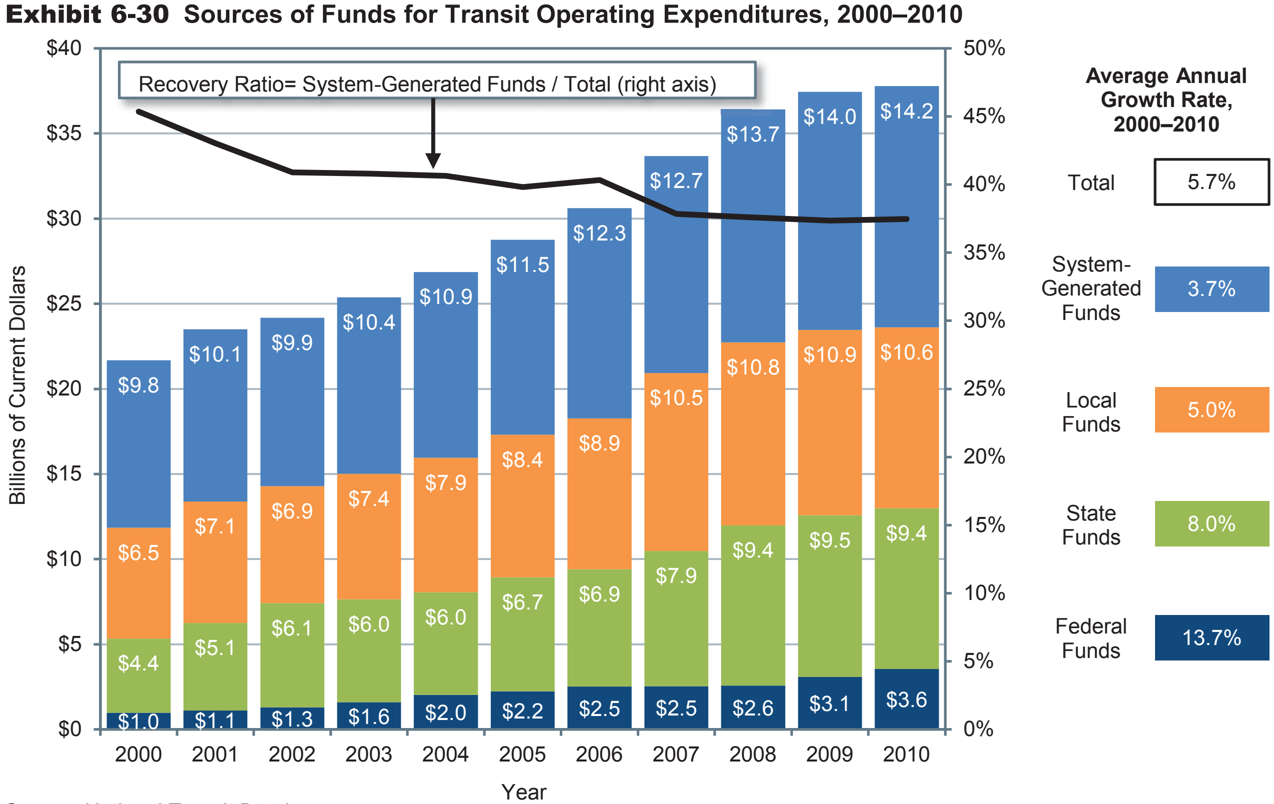
facilities. Facilities also include investment in building structures, climate control, parking, yard track, vehicle and facilities maintenance equipment, furniture, office equipment, and computer systems.

Other capital includes capital costs associated with general administration facilities, furniture, equipment that is not an integral part of buildings and structures, data processing equipment (including computers and peripheral devices whose sole use is in data processing operations), and shelters located at on-street bus stops.

Operating Expenditures

Transit operating expenditures include wages, salaries, fuel, spare parts, preventive maintenance, support services, and certain leases used in providing transit service. As indicated in *Exhibit 6-30*, $37.8 billion

Exhibit 6-30 Sources of Funds for Transit Operating Expenditures, 2000–2010



Source: National Transit Database.

was available for operating expenses in 2010, the Federal share of which has increased from the 2008 level of 7.1 percent to 9.4 percent. The share generated from system revenues remained relatively stable from 37.6 percent in 2008 to 37.5 percent in 2010. The State share decreased slightly from 25.8 percent in 2008 to 24.9 percent in 2010. The local share of operating expenditures decreased slightly from 29.5 percent in 2008 to 28.2 percent in 2010.

Q&A

What happens after the census?

TEA-21 mandated that Federal funding to transit systems in urbanized areas with populations over 200,000 be used only for capital expenses and preventive maintenance, and not for operating expenses. Formula grant funds to urbanized areas with populations of less than 200,000 were still allowed to be used for operating expenses. As a result of the 2000 census, 56 areas were reclassified as urbanized areas with populations of more than 200,000. (These reclassifications were announced by the Census Department in May 2002.) Transit agencies operating in these areas were slated to lose their eligibility to use Federal formula funding to finance transit operations starting in FY 2003. The Transit Operating Flexibility Act of 2002 amended Section 5307 of 49 USC to allow transit systems that were in these areas to continue to use their formula funds for operating expenses as well as for capital expenses in FY 2003, despite their change in status. This change was extended by the Surface Transportation Extension Act of 2003. Under SAFETEA-LU these transit agencies may continue to use formula funds for operating expenses in FY 2005 at 100 percent of their FY 2002 apportionment, in FY 2006 at 50 percent of their FY 2002 apportionment, and in FY 2007 at 25 percent of their FY 2002 apportionment. The impact of the 2010 census did not take place until the 2013 apportionment. Legislative responses to these reclassifications have not yet been considered.

Operating Expenditures by Transit Mode

As shown in *Exhibit 6-31*, total transit operating expenditures were $35.1 billion in 2010. These expenditures increased at an average annual rate of 5.8 percent between 2000 and 2010 (in current-year dollars). Light rail and demand response modes have experienced the largest percentage increase in operating expenditures during this period. This is due to relatively greater investment in new light rail and demand response capacity over the past 10 years.

Exhibit 6-31 Transit Operating Expenditures by Mode, 2000–2010

	Expenditures, Millions of Current Dollars						
Year	Motor Bus	Heavy Rail	Commuter Rail	Light Rail	Demand Response	Other	Total
2000	$11,026	$3,931	$2,679	$592	$1,225	$549	**$20,003**
2001	$11,814	$4,180	$2,854	$676	$1,410	$595	**$21,529**
2002	$12,586	$4,267	$2,995	$778	$1,636	$643	**$22,905**
2003	$13,316	$4,446	$3,173	$754	$1,779	$718	**$24,185**
2004	$13,790	$4,734	$3,436	$826	$1,902	$739	**$25,427**
2005	$14,666	$5,145	$3,657	$978	$2,071	$721	**$27,238**
2006	$15,796	$5,287	$3,765	$1,070	$2,286	$820	**$29,025**
2007	$16,812	$5,888	$4,001	$1,163	$2,539	$901	**$31,304**
2008	$17,963	$6,129	$4,294	$1,259	$2,861	$975	**$33,479**
2009	$18,313	$6,311	$4,538	$1,393	$3,053	$1,030	**$34,638**
2010	$18,399	$6,370	$4,595	$1,499	$3,171	$1,037	**$35,071**
Percent of Total							
2000	55.1%	19.7%	13.4%	3.0%	6.1%	2.7%	**100.0%**
2010	52.5%	18.2%	13.1%	4.3%	9.0%	3.0%	**100.0%**

Source: National Transit Database.

Operating Expenditures by Type of Cost

In 2010, $18.6 billion—or 53.1 percent of total transit operating expenditures—went toward vehicle operations. Smaller amounts were expended on maintenance and administration; these expenses, which have virtually been the same for the last several years, are broken down across cost categories in *Exhibit 6-32.*

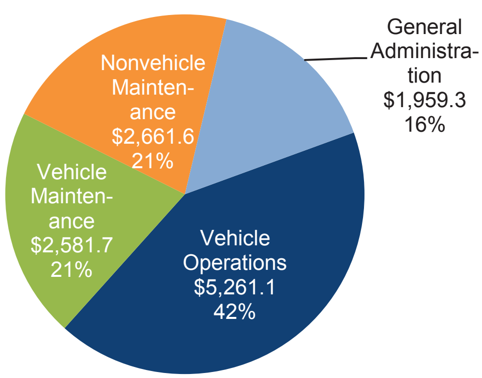
Exhibit 6-32 Operating Expenditures by Mode and Type of Cost, 2010

Mode	Vehicle Operations	Vehicle Maintenance	Nonvehicle Maintenance	General Administration	Total
	Distribution of Expenditures, Millions of Dollars				
Motor Bus	$10,788	$3,717	$773	$3,121	**$18,399**
Heavy Rail	$2,789	$1,113	$1,577	$890	**$6,370**
Commuter Rail	$1,860	$1,161	$822	$752	**$4,595**
Light Rail	$612	$308	$262	$317	**$1,499**
Demand Response	$2,016	$409	$85	$661	**$3,171**
Other	$561	$170	$80	$226	**$1,037**
Total	**$18,625**	**$6,878**	**$3,600**	**$5,968**	**$35,071**
Percent of All Modes	53.1%	19.6%	10.3%	17.0%	100.0%

Source: National Transit Database.

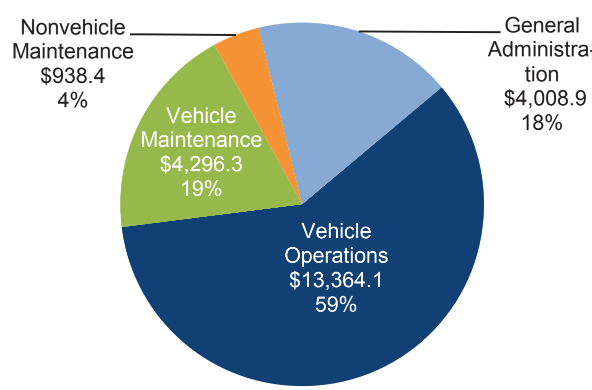
Exhibits 6-33 and *6-34* illustrate how road and rail operations have inherently different cost structures because, in most cases, roads are not paid for by the transit provider, but tracks are. A significantly higher percentage of expenditures for rail modes of transportation are classified as nonvehicle maintenance, corresponding to the repair and maintenance costs of fixed guideway systems.

Exhibit 6-33 Rail Operating Expenditures by Type of Cost, Millions of Dollars



Source: National Transit Database.

Exhibit 6-34 2010 Nonrail Operating Expenditures by Type of Cost, Millions of Dollars



Source: National Transit Database.

Operating Expenditures per Vehicle Revenue Mile

Operating expenditures per vehicle revenue mile (VRM) is one measure of financial or cost efficiency. It shows the expense of operating a transit vehicle in revenue service. As shown in *Exhibit 6-35*, operating expenditures per VRM for all transit modes combined was $8.95 in 2010; the average annual increase in operating expenditures per VRM for all modes combined between 2000 and 2010 was 1.3 percent in constant dollars.

As shown in *Exhibit 6-36,* analysis of NTD reports for urbanized areas with greater than 1 million in population shows that the growth in operating expenses is led by the cost of fringe benefits, which have

Exhibit 6-35 Operating Expenditures per Vehicle Revenue Mile, 2000–2010 (Constant Dollars)

Year	Motor Bus[1]	Heavy Rail	Commuter Rail	Light Rail	Demand Response	Other[2]	Total
2000	$7.84	$8.52	$13.55	$14.43	$3.40	$6.33	**$7.83**
2001	$7.94	$8.66	$13.81	$15.58	$3.52	$6.62	**$7.94**
2002	$8.13	$8.52	$13.92	$15.64	$3.75	$6.73	**$8.05**
2003	$8.36	$8.58	$14.30	$14.46	$3.86	$7.52	**$8.21**
2004	$8.43	$8.73	$14.72	$14.27	$3.90	$5.99	**$8.25**
2005	$8.68	$9.14	$14.72	$16.06	$3.90	$5.20	**$8.43**
2006	$8.92	$8.99	$14.15	$15.81	$4.07	$5.53	**$7.88**
2007	$9.12	$9.66	$14.12	$14.79	$4.12	$5.41	**$8.70**
2008	$9.40	$9.57	$14.22	$14.92	$4.26	$5.01	**$8.80**
2009	$9.39	$9.55	$14.67	$15.82	$4.26	$4.58	**$8.77**
2010	$9.60	$9.84	$14.60	$16.36	$4.42	$4.49	**$8.95**
Average Annual Rate of Change							
2010/2000	2.0%	1.4%	0.8%	1.3%	2.7%	-3.4%	**1.3%**

[1] Note that annual changes in operating expense per capacity-equivalent VRM and unadjusted motor bus operating expenditures are consistent with those shown in Exhibit 6-31.

[2] Automated guideway, Alaska railroad, cable car, ferryboat, inclined plane, monorail, Público, trolleybus, and vanpool.

Source: National Transit Database.

been going up at a rate of 3.8 percent per year above inflation (constant dollars) since 2000. By comparison, average salaries at these 10 agencies grew at an inflation-adjusted rate of only 0.4 percent per year in that period. FTA does not collect data on the different components of fringe benefits, but increases in the cost of medical insurance drive growth rates in fringe benefits across the economy and likely drive the growth in this category.

Exhibit 6-36 Growth in Operating Costs—UZAs over 1 million*, 2000–2010

Cost Component	Average Cost per Mile, Constant Dollars											% Increase	
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2000–2010	Average Annual
Salaries	$3.49	$3.48	$3.58	$3.62	$3.56	$3.51	$3.56	$3.58	$3.61	$3.62	$3.63	4%	0.4%
Fringe Benefits	$2.12	$2.17	$2.31	$2.49	$2.62	$2.69	$2.69	$2.85	$2.81	$2.93	$3.07	45%	3.8%
Labor Cost	$5.61	$5.65	$5.89	$6.11	$6.18	$6.20	$6.25	$6.44	$6.42	$6.55	$6.69	19%	1.8%
Total	$11.21	$11.29	$11.78	$12.21	$12.36	$12.41	$12.50	$12.88	$12.84	$13.10	$13.39	19%	1.8%

**MTA New York City, Chicago Transit Authority, Los Angeles County Metropolitan Transportation Authority, Washington Metropolitan Area Transit Authority, Massachusetts Bay Transportation Authority, Southeastern Pennsylvania Transportation Authority, New Jersey Transit Corporation, San Francisco Municipal Railway, Metropolitan Atlanta Rapid Transit Authority, and Maryland Transit Administration.*

Source: National Transit Database.

Operating expenditures per capacity-equivalent VRM is a better measure of comparing cost efficiency among modes than operating expenditures per VRM because it adjusts for passenger-carrying capacities. As demonstrated by the data in *Exhibit 6-37*, rail systems are more cost efficient in providing service than nonrail systems, once investment in rail infrastructure has been completed. Based on operating costs alone, heavy rail is the most efficient at providing transit service, and demand response systems are the least efficient. Annual changes in operating expense per capacity-equivalent VRM are not comparable across modes because average capacities for all vehicle types are adjusted separately each year based on reported fleet averages.

Exhibit 6-37 **Operating Expenditures per Capacity-Equivalent Vehicle Revenue Mile by Mode, 2000–2010 (Constant Dollars)**

Year	Motor Bus	Heavy Rail	Commuter Rail	Light Rail	Demand Response	Other	Total
2000	$7.84	$3.61	$5.81	$5.73	$18.86	$9.66	**$6.46**
2001	$7.94	$3.67	$5.93	$6.18	$19.56	$10.45	**$6.42**
2002	$8.13	$3.61	$5.98	$6.21	$20.85	$10.16	**$6.40**
2003	$8.36	$3.46	$5.61	$5.38	$21.43	$11.30	**$6.48**
2004	$8.43	$3.52	$5.78	$5.31	$22.95	$10.48	**$6.54**
2005	$8.68	$3.68	$4.80	$5.83	$23.51	$9.66	**$6.70**
2006	$8.92	$3.62	$4.62	$5.74	$24.49	$10.69	**$6.79**
2007	$9.12	$3.91	$4.64	$5.44	$24.59	$10.49	**$6.76**
2008	$9.40	$3.87	$4.67	$5.49	$25.39	$13.22	**$6.93**
2009	$9.39	$4.54	$5.33	$6.32	$25.80	$11.47	**$7.50**
2010	$9.60	$3.98	$5.34	$5.95	$25.48	$11.16	**$7.24**
Compound Annual Growth Rate							
2010/2000	2.0%	1.0%	-0.8%	0.4%	3.1%	1.5%	**1.1%**

Source: National Transit Database.

Operating Expenditures per Passenger Mile

Operating expense per passenger mile is an indicator of the cost effectiveness of providing a transit service. It shows the relationship between service inputs as expressed by operating expenses and service consumption as expressed by passenger miles traveled. Operating expenditures per passenger mile for all transit modes combined increased at an average annual rate of 1.8 percent between 2000 and 2010 (from $0.56 to $0.67). These data are shown in *Exhibit 6-38*.

Exhibit 6-38 **Operating Expenditures per Passenger Mile, 2000–2010 (Constant Dollars)**

Year	Motor Bus	Heavy Rail	Commuter Rail	Light Rail	Demand Response	Other*	Total
2000	$0.73	$0.36	$0.36	$0.55	$2.61	$0.61	**$0.56**
2001	$0.74	$0.36	$0.37	$0.58	$2.76	$0.63	**$0.57**
2002	$0.78	$0.38	$0.38	$0.65	$3.03	$0.66	**$0.60**
2003	$0.81	$0.39	$0.39	$0.65	$3.05	$0.66	**$0.63**
2004	$0.84	$0.38	$0.40	$0.64	$3.11	$0.61	**$0.63**
2005	$0.84	$0.40	$0.43	$0.64	$3.13	$0.59	**$0.64**
2006	$0.84	$0.39	$0.39	$0.62	$3.27	$0.62	**$0.63**
2007	$0.86	$0.38	$0.38	$0.63	$3.42	$0.63	**$0.63**
2008	$0.87	$0.37	$0.40	$0.62	$3.47	$0.58	**$0.64**
2009	$0.88	$0.38	$0.41	$0.64	$3.50	$0.58	**$0.65**
2010	$0.89	$0.39	$0.43	$0.69	$3.63	$0.57	**$0.67**
Compounded Annual Growth Rate							
2010/2000	2.0%	0.9%	1.8%	2.2%	3.3%	-0.8%	**1.8%**

** Automated guideway, cable car, ferryboat, inclined plane, jitney, monorail, Público, trolleybus, aerial tramway, and vanpool.*

Source: National Transit Database.

Farebox Recovery Ratios

The farebox recovery ratio represents farebox revenues as a percentage of total transit operating costs. It measures users' contributions to the variable cost of providing transit services and is influenced by the number of riders, fare structure, and rider profile. Low regular fares, the high availability and use of

discounted fares, and high transfer rates tend to result in lower farebox recovery ratios. Farebox recovery ratios for 2004 to 2010 are provided in *Exhibit 6-39*. The average farebox recovery ratio over this period for all transit modes combined was 34.6 percent; heavy rail had the highest average farebox recovery ratio at 59.9 percent. Farebox recovery ratios for total costs are not provided because capital investment costs are not spread evenly across years. Rail modes have farebox recovery ratios for total costs that are significantly lower than for operating costs alone because of these modes' high level of capital costs.

Exhibit 6-39 Farebox Recovery Ratio by Mode, 2004–2010

Year	Motor Bus	Heavy Rail	Commuter Rail	Light Rail	Demand Response	Other[2]	Total
2004[1]	27.9%	61.3%	47.0%	26.2%	9.6%	36.2%	**35.5%**
2005[1]	27.6%	58.4%	47.2%	25.4%	9.5%	12.6%	**34.8%**
2006[1]	26.6%	60.9%	49.4%	27.4%	9.3%	34.3%	**34.8%**
2007	26.6%	56.8%	49.5%	26.6%	8.2%	35.3%	**34.0%**
2008	26.3%	59.4%	50.3%	29.3%	7.5%	32.7%	**34.1%**
2009	26.7%	60.2%	47.9%	28.0%	7.8%	34.9%	**34.2%**
2010	26.7%	62.3%	48.5%	27.5%	7.9%	37.0%	**34.7%**
Average	**26.9%**	**59.9%**	**48.5%**	**27.2%**	**8.5%**	**31.9%**	**34.6%**

[1] Note that the ratios presented in this exhibit were calculated differently than the ratios presented in the 2008 C&P Report; therefore, they are not totally comparable. The ratios presented here were calculated using data from NTD data table 26, "Fares per Passenger and Recovery Ratio", which is available at www.ntdprogram.gov/ntdprogram/data.htm.

[2] Automated guideway, Alaska railroad, cable car, ferryboat, inclined plane, jitney, monorail, Público, trolleybus, aerial tramway, and vanpool.

Source: National Transit Database.

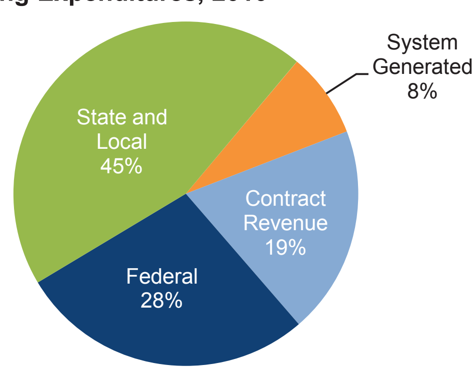
Rural Transit

Since 1978, the Federal government has contributed to the funding of transit in rural areas (i.e., areas with populations of less than 50,000). These rural areas are estimated to account for approximately 36 percent of the U.S. population and 38 percent of the transit-dependent population.

Funding for rural transit is currently provided through 49 U.S.C. Section 5311, the Rural Formula Grant Program. Rural transit funding was increased substantially with passage of TEA-21 and continued to increase under SAFETEA-LU. Federal funding for rural transit was $240 million in the last year of TEA-21, FY 2004, and reached $465 million in FY 2009 under SAFETEA-LU. States may transfer additional funds to rural transit from highway projects or formula transit funds for small urbanized areas.

As shown in *Exhibit 6-40*, 28 percent of rural transit authorities' operating budgets come from Federal funds. State and local governments cover 45 percent of their rural transit operating budgets through a combination of dedicated State and local taxes, appropriations from State general revenues, and allocations from other city and county funds. Contract revenue, defined as reimbursement from a private entity (profit or nonprofit) for the provision of transit service, accounts for 19 percent of rural transit operating budgets. Fares accounted for only 8 percent, close to the average farebox recovery rate for demand response service (which constitutes most of rural transit). In 2010, the total value of rural transit operating budgets reported to the NTD was $1.25 billion.

Exhibit 6-40 Rural Transit Funding Sources for Operating Expenditures, 2010



Source: National Transit Database.

PART II

Investment/Performance Analysis

Introduction

Chapters 7 through 10 present and analyze future capital investment scenario estimates for highways, bridges, and transit. These chapters provide general investment benchmarks as a basis for the development and evaluation of transportation policy and program options. The 20-year investment scenario estimates shown in these chapters reflect the total capital investment from all sources that is projected to be required to achieve certain levels of performance. **They do not directly address specific public or private revenue sources that might be used to finance the investment under each scenario, nor do they identify how much might be contributed by each level of government.**

These four investment-related chapters include the following analyses:

Chapter 7, **Potential Capital Investment Impacts**, analyzes the projected impacts of alternative levels of future investment on measures of physical condition, operational performance, and benefits to system users. Each alternative pertains to investment from 2011 through 2030, and is presented as an annual average level of investment (highway and transit) and as the annual rates of increase or decrease in investment that would produce that annual average (highway only). Both the level and rate of growth in investment are measured using constant 2010 dollars.

Chapter 8, **Selected Capital Investment Scenarios**, examines several scenarios distilled from the investment alternatives considered in Chapter 7. Some of the scenarios are oriented around maintaining different aspects of system condition and performance or achieving a specified minimum level of performance, while others link to broader measures of system user benefits. The scenarios included in this chapter are intended to be illustrative and do not represent comprehensive alternative transportation policies; U.S. Department of Transportation (DOT) does not endorse any of these scenarios as a target level of investment.

Chapter 9, **Supplemental Scenario Analysis**, explores some of the implications of the scenarios presented in Chapter 8 and contains some additional policy-oriented analyses addressing issues not covered in Chapters 7 and 8. As part of this analysis, highway projections from previous editions of the C&P report are compared with actual outcomes to throw light on the value and limitations of the projections presented in this edition.

Chapter 10, **Sensitivity Analysis**, explores the impacts on scenario projections of varying some of the key assumptions. The investment scenario projections in this report are developed using models that evaluate current system condition and operational performance and make 20-year projections based on assumptions about future travel growth and a variety of engineering and economic variables. The accuracy of these projections depends, in large part, on the realism of these assumptions. To address the uncertainty concerning which assumptions would be most realistic, Chapter 10 presents sensitivity analyses that vary the discount rate, the value of travel time savings, and other assumed parameter values. Other sources of uncertainty in the modeling procedures are discussed further below.

Unlike Chapters 1 through 6, which largely present highway and transit statistics drawn from other sources, the investment scenario projections presented in these chapters (and the models used to create the projections) were developed exclusively for the C&P report. The procedures for developing the investment scenario estimates have evolved over time to incorporate recent research, new data sources, and improved estimation techniques. The methodologies used to analyze investment for highways, bridges, and transit are discussed in greater detail in Appendices A, B, and C.

The combination of engineering and economic analysis in this part of the report is consistent with the movement of transportation agencies toward asset management, value engineering, and greater consideration of cost effectiveness in decision making. The economic approach to transportation investment is discussed in greater detail at the end of this section.

Capital Investment Scenarios

The 20-year capital investment scenario projections shown in this report reflect complex technical analyses that attempt to predict the impact that capital investment may have on the future conditions and performance of the transportation system. These scenarios are intended to be illustrative, and the U.S. DOT does not endorse any of them as a target level of investment. Where practical, supplemental information has been included to describe the impacts of other possible investment levels.

This report does not attempt to address issues of cost responsibility. The investment scenarios predict the impact that particular levels of combined Federal, State, local, and private investment might have on the overall conditions and performance of highways, bridges, and transit. While Chapter 6 provides information on what portion of highway investment has come from different revenue sources in the past, the report does not make specific recommendations about how much could or should be contributed by each level of government or the private sector in the future.

In considering the system condition and performance projections in this report's capital investment scenarios, it is important to note that they represent what *could* be achievable assuming a particular level of investment, rather than what *would* be achieved. The models used to develop the projections generally assume that, when funding is constrained, the benefit-cost ratio (BCR) establishes the order of precedence among potential capital projects, with projects having higher BCRs being selected first. In actual practice, the BCR generally omits some types of benefits and costs because of difficulties in valuing them monetarily, and these other benefits and costs can and do affect project selection.

Also, some potential capital investments selected by the models, regardless of their economic merits or impact on conditions and performance, may be infeasible for political or other reasons. As a result, the supply of feasible cost-beneficial projects could be lower than the levels estimated by the modeling assumptions of some scenarios.

Highway and Bridge Investment Scenarios

Projections for future conditions and performance under alternative potential levels of investment are developed independently for highways and bridges in Chapter 7 using separate models and techniques, and then combined for selected investment scenarios in Chapter 8. Investments in bridge repair, rehabilitation, and replacement are modeled by the National Bridge Investment Analysis System (NBIAS); those in capacity expansion and the highway resurfacing and reconstruction component of system rehabilitation are modeled by the Highway Economic Requirements System (HERS). Although HERS was primarily designed to analyze highway segments, it also factors in the costs of expanding bridges and other structures when deciding whether to add lanes to a highway segment. Some elements of highway investment spending are modeled by neither HERS nor NBIAS. Chapter 8 factors these elements into the investment levels associated with each scenario using scaling procedures external to the models. The scenario investment levels are estimates of the amount of future capital spending required to meet the performance goals specified in the scenarios.

Chapter 8 uses consistent performance criteria to create separate but parallel investment scenarios for all Federal-aid highways, the National Highway System, and the Interstate System. Corresponding scenarios are also presented for all roads system-wide, but projections for these scenarios are less reliable because data coverage is more limited off the Federal-aid highways. Although the NBIAS database includes information on all bridges, the Highway Performance Monitoring System (HPMS) database, on which the HERS model relies, includes detailed information only on Federal-aid highways; for the scenarios based on all roads, non-model-based estimates must be generated for roads functionally classified as rural minor collectors, rural local, or urban local. For system-wide and Federal-aid highway investment, Chapter 8 includes an alternative set of scenarios that assume future lower reduce the vehicle miles traveled (VMT) growth forecasts derived from HPMS to match the actual trend in VMT growth from 1995 to 2010.

The **Sustain 2010 Spending scenario** projects the potential impacts of sustaining capital spending at 2010 base-year levels in constant dollar terms over the 20-year period 2011 through 2030. The **Maintain Conditions and Performance scenario** assumes that combined highway capital investment by all levels of government gradually changes in constant dollar terms over 20 years to the point at which selected performance indicators in 2030 are maintained at their 2010 base year levels. For this edition, the HERS component of the scenario is defined as the average of the investment level required to maintain average pavement roughness and the investment level required to maintain the average amount of congestion delay per VMT (the scenario is defined around the average of the investment level required to maintain each); the NBIAS component is defined as the investment level required to maintain the average sufficiency rating for bridges. The investment levels for the **Improve Conditions and Performance scenario** are determined by identifying the highest rate of annual spending growth for which potentially cost-beneficial highway and bridge improvements can be identified. This scenario represents an "investment ceiling" above which it would not be cost-beneficial to invest, even if available funding were unlimited. The portion of this scenario directed toward addressing engineering deficiencies on pavements and bridges is described as the **State of Good Repair benchmark**.

The **Intermediate Improvement scenario** is included in Chapter 8 in recognition that any investment above the level of the **Maintain Conditions and Performance scenario** described above should theoretically improve conditions and performance. The HERS portion of this scenario reflects a level of investment at which all potential improvements with a BCR of 1.5 or higher could be funded (in contrast to the **Improve Conditions and Performance scenario**, which utilizes a minimum BCR of 1.0). The NBIAS portion of this scenario assumes an increase in spending sufficient to achieve, for illustration, half the improvement in the average sufficiency index projected under the **Improve Conditions and Performance scenario**.

Transit Investment Scenarios

The transit section of Chapter 7 evaluates the impact of varying levels of capital investment on various measures of condition and performance, while the transit section of Chapter 8 provides a more in-depth analysis of specific investment scenarios.

The **Sustain 2010 Spending scenario** projects the potential impacts of sustaining preservation and expansion spending at 2010 base-year levels in constant dollar terms over the 20-year period of 2011 through 2030. The scenario applies benefit-cost analysis to prioritize investments within this constrained budget target.

The **State of Good Repair benchmark** projects the level of investment needed to bring all assets to a state of good repair over the next 20 years, defined as asset condition ratings of 2.5 or higher on a 5-point scale (Chapter 3 discusses these ratings). This scenario is focused solely on the preservation of existing assets and does not apply a benefit-cost screen.

The **Low Growth scenario** adds a system expansion component on top of the system preservation needs associated with the **State of Good Repair benchmark**. The goal of this scenario is to preserve existing assets and expand the transit asset base to support projected ridership growth over 20 years as forecast by metropolitan planning organizations. The **High Growth scenario** incorporates a more extensive expansion of the existing transit asset base to support a higher annual rate of growth consistent with that experienced between 1995 and 2010. Both of these scenarios incorporate a benefit-cost test for evaluating potential investments.

Comparisons Between Report Editions

When comparing capital investment scenarios presented in different editions of the C&P report, several considerations should be taken into account:

Scenario definitions have been modified over time. Between the present edition and the 2010 C&P report, the target performance indicators in the **Maintain Conditions and Performance scenarios** have changed. In the 2010 edition, those indicators were average speed for investments modeled by HERS and the backlog of potential cost-beneficial bridge investments modeled by NBIAS. In the present edition, the corresponding indicators are pavement roughness/congestion delay and the average sufficiency rating for bridges. In addition, the expansion of the National Highway System under the Moving Ahead for Progress in the 21st Century Act (MAP-21) means that the scenarios for that system considered in this edition of the C&P report are not comparable to those considered in the 2010 edition.

The scenarios for highway and bridge investment now present alternate sets of projections applying the 15-year historic trend in VMT growth to the assumed rate of future growth, whereas all recent editions of the report have exclusively used the traffic growth forecasts from HPMS. This change makes the highway and bridge investment scenarios more comparable to the transit investment scenarios, which introduced an alternative trend-based ridership growth forecast in the 2010 edition.

The analytical tools and data used in generating the scenarios have been refined and improved over time.

Q&A

Why do the scenarios presented in Part II of this report focus on the NHS as expanded by MAP-21, rather than the NHS as it existed in 2010?

While the data presented in Part I of this report naturally focus on the NHS as it existed in 2010, presenting investment scenarios through the year 2030 for that version of the NHS would provide little value going forward given that MAP-21 significantly expanded the size of the system.

While basing the Part II 20-year investment scenarios on the NHS as expanded by MAP-21 requires readers to be mindful that the 2010 data presented in Part I relate to the pre-expanded system, this approach was deemed preferable to the alternative of simply excluding NHS-based scenarios from this edition entirely.

The base year of the analysis advances two years between successive editions of this biennial report. During this period, changes in many real-world factors can affect the investment scenario estimates. Among these factors are construction costs and other prices, conditions and performance of the highway and transit systems, expansion of the system asset base, and changes in technology (such as improvements in motor vehicle fuel economy). While this issue is relevant to all scenarios, it is particularly significant for scenarios aimed at maintaining base-year conditions.

Selected comparisons of this report's capital investment scenarios for highways with those from previous editions are presented in Chapter 9. Chapter 9 also includes analyses that look back at the highway and bridge scenarios presented in the 1991 C&P Report to see how its projections of future conditions and performance have lined up with what has actually occurred over time, taking into account factors such as changes in capital spending and travel growth.

The Economic Approach to Transportation Investment Analysis

The methods and assumptions used to analyze future highway, bridge, and transit investment scenarios are continuously evolving. Since the beginning of the highway report series in 1968, improvements in the data and techniques relating to the highway investment scenarios have resulted from innovations in analytical methods, new data and evidence, and changes in transportation planning objectives. Estimates of future highway investment requirements, as reported in the 1968 *National Highway Needs Report to Congress*, began as a combined "wish list" of State highway "needs." As the focus of national highway investment changed from system expansion to management of the existing system during the 1970s, national engineering standards were defined and applied to identify system deficiencies, and the investments necessary to remedy these deficiencies were estimated. By the end of the decade, a comprehensive database, the HPMS, had been developed to allow monitoring of highway system conditions and performance nationwide.

By the early 1980s, a sophisticated simulation model, the HPMS Analytical Process (HPMS-AP), was available to evaluate the impact of alternative investment strategies on system conditions and performance. The procedures used in the HPMS-AP were based on engineering principles. Engineering standards were applied to determine which system attributes were considered deficient, and improvement option packages were developed using standard engineering practices to potentially correct given deficiencies, but without consideration of comparative economic benefits and costs.

In 1988, the Federal Highway Administration embarked on a long-term research and development effort to produce an alternative simulation procedure combining engineering principles with economic analysis, culminating in the development of the HERS. The HERS model was first utilized to develop one of the two highway investment scenarios presented in the 1995 C&P Report. In subsequent reports, HERS has been used to develop all of the highway investment scenarios.

Executive Order 12893, "Principles for Federal Infrastructure Investments," issued on January 26, 1994, directs that Federal infrastructure investments be selected on the basis of a systematic analysis of expected benefits and costs. This order provided additional momentum for the shift toward developing analytical tools that incorporate economic analysis into the evaluation of investment requirements.

In the 1997 C&P Report, the Federal Transit Administration introduced the Transit Economics Requirements Model (TERM), which was used to develop both of the transit investment scenarios. TERM incorporates benefit-cost analysis into its determination of transit investment levels.

The 2002 C&P Report introduced the NBIAS, incorporating economic analysis into bridge investment modeling for the first time.

The Economic Approach in Theory and Practice

The economic approach to transportation investment entails analysis and comparison of benefits and costs. Investments that yield benefits whose values exceed their costs have the potential to increase societal welfare and are thus considered "economically efficient." For such analysis to be reliable, it must give adequate consideration to the range of possible benefits and costs and the range of possible investment alternatives.

Which Benefits and Costs Should Be Considered?

A comprehensive benefit-cost analysis of a transportation investment would consider all impacts of potential significance for society and value them in monetary terms to the extent feasible. For some types of impacts, monetary valuation is facilitated by the existence of observable market prices. Such prices are generally available for inputs to the provision of transportation infrastructure, such as concrete for building highways

or buses purchased for a transit system. The same is true for some types of benefits from transportation investments, such as savings in business travel time, which are conventionally valued at a measure of average hourly labor cost of the travelers.

For some other types of impacts, market prices are not available but monetary values can be reasonably inferred from behavior or expressed preferences. In this category are savings in non-business travel time and reductions in risk of crash-related fatality or other injury. As discussed in Chapter 10 (under "Value of a Statistical Life"), what is inferred is the amount that people would typically be willing to pay per unit of improvement, e.g., per hour of non-business travel time saved. These values are combined with estimates of the magnitude of the improvement (or, as may happen, deterioration).

For other impacts, monetary valuation may not be possible because of problems with reliably estimating the magnitude of the improvement, putting a monetary value on the improvement, or both. Even when possible, reliable monetary valuation may require time and effort that would be out of proportion to the likely importance of the impact concerned. Benefit-cost analyses of transportation investments will thus typically omit to value certain impacts that could nevertheless be of interest.

The benefit-cost analyses performed by the models used in this report to evaluate levels of transportation investment—HERS, NBIAS, and TERM—each omit various types of investment impacts. To some extent, this reflects the national coverage of their primary databases; while consistent with this report's focus on the Nation's highways and transit systems, such broad geographic coverage requires some sacrifice of detail to stay within feasible budgets for data collection. In the future, technological progress in data collection as well as growing demand for data for performance management systems for transportation infrastructure will likely yield richer national databases.

In addition, U.S. DOT will continue to explore other avenues for addressing impacts not captured by the suite of models used for the C&P report. One approach is to have the models represent impacts in ways that are sufficiently simplified to demand no more data than are available. This approach was taken to represent within HERS the impacts of traffic disruptions resulting from road construction. Another approach that U.S. DOT will continue to explore for the C&P report is to supplement the findings from HERS, NBIAS and TERM with evidence from other sources. This could shed additional light on various environmental, health, and community impacts of highway and transit investments. Examples include environmental impacts of increased water runoff from highway pavements, barrier effects of highways for human and animal populations, the health benefits from the additional walking activity when travelers go by transit rather than by car, and other impacts related to livability. Another effect not considered by the DOT models, but which may be significant for some transportation investments, is the boost to economic competitiveness that results when travel times among competing producers are lessened. Faced with stiffer competition from rivals in other locations, producers may become more efficient and lower prices.

What Alternatives Should Be Analyzed?

In defining the investment alternatives in a benefit-cost analysis of transportation investments, it is important to make the range of alternatives sufficiently broad. For some transit and highway projects, this would require consideration of cross-modal alternatives. Transit and highway projects can be complements, as when the addition of high-occupancy toll lanes to a freeway creates a demand for bus express services; they can also be substitutes, as when construction of a light rail line lessens the demand for travel on a parallel freeway. In contrast, HERS and TERM each focus on investment in just one mode, and to properly incorporate a cross-modal perspective would require a major increase in the level of detail in their supporting databases that, as was noted above, necessarily sacrifice detail to provide national-level coverage. For the foreseeable future, the best way to address this deficiency in future editions of the C&P report would be through review of evidence obtained from more regionally focused analyses using other modeling frameworks.

Beyond related cross-modal investment possibilities, economic evaluations of investments in highways or transit should also attempt to consider related public choices, such as policies for travel demand management and local zoning, or investment in other infrastructure.

Several previous editions of the C&P report presented the HERS modeling of highway investment combined with system-wide highway congestion pricing. Although this modeling indicated that pricing has potential to substantially reduce the amount of highway investment that would be cost-beneficial, a subsequent review of the methodology found significant limitations, which reflected in large part the lack of transportation network detail in the HPMS database. For this reason, and because the estimated effects of congestion pricing would likely have differed little from that reported in previous editions of the C&P report, the present edition does not repeat this analysis. Also omitted from this edition are HERS analyses of scenarios that adjusted future motor fuel taxes, or other taxes related to highway use, to produce changes in revenue offsetting any increases in highway investment relative to the base year level. The inclusion of this mechanism had minimal effects on the HERS results.

Future editions of the C&P report could further explore the implications for highway and transit investments of congestion pricing and other regionally or locally focused measures with which these investments could be packaged. However, because the databases supporting HERS and TERM lack regional economic and transportation network data, these models are probably not the best vehicles for such analysis. More could probably be learned from regional case studies that use alternative modeling frameworks and databases.

Measurement of Costs and Benefits in "Constant Dollars"

Benefit-cost analyses normally measure all benefits and costs in "constant dollars", i.e., at the prices prevailing in some base year that is normally near the year when the analysis is released. Future price changes may be difficult to forecast, and benefits and costs measured in base-year prices are more comprehensible.

In the simplest form of constant dollar measurement, conversion of any quantity to a dollar value is done at that quantity's base-year price. Future savings in gallons of gasoline, for example, are monetized at the average price per gallon of gasoline in the base year (with the price possibly measured net of excise tax, as in HERS). This approach is still quite common in benefit-cost analysis and was the general practice in pre-2008 editions of the C&P report. It is important to note that this approach does not assume a future without inflation, but simply that ratios among prices will remain at their base-year levels. With relative prices constant, whether a benefit-cost analysis uses actual base-year prices or those prices uniformly inflated at a projected rate of inflation is a purely a presentational issue.

An alternative approach is called for when significant changes in the relative price of a quantity important to the analysis can be predicted with sufficient confidence. What constitutes sufficient confidence is a judgment call, but some predictions carry official weight. The Energy Information Administration's *Annual Energy Outlook* forecasts changes in motor fuel prices relative to the consumer price index (CPI) 25 years out. The 2008 edition of the C&P report incorporated these CPI-deflated forecasts in the highway investment scenarios, a practice that resumes in this edition. The 2010 edition incorporated CPI-deflated forecasts of the marginal damage cost of CO_2 emissions, taken from a 2010 report by a Federal inter-agency working group, into its baseline HERS simulations; the 2013 edition continues this approach (Interagency Working Group on Social Cost of Carbon. February 2010. Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866, http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf).

The modeling presented in Part II of the present edition of the C&P report moves allows for still other changes in relative prices. Chapter 10 includes sensitivity tests to examine the effects on some of the modeling results of assuming growth in the real (i.e., CPI-deflated) values of travel time savings and crash

reductions, as now recommended under guidance for U.S. DOT analyses issued in 2011 by the Office of Economic and Strategic Analysis under the Assistant Secretary for Transportation Policy. This guidance recommends assuming that these values will grow over time at specified rates that are based on expected growth in real income.

Notwithstanding these allowances for likely changes in prices relative to the CPI, the analysis in this report may be considered to measure benefits and costs in constant 2010 dollars. Office of Management and Budget guidance on benefit-cost analysis defines "real or constant dollar values" as follows:

> Economic units measured in terms of constant purchasing power. A real value is not affected by general price inflation. Real values can be estimated by deflating nominal values with a general price index, such as the implicit deflator for Gross Domestic Product or the Consumer Price Index (OMB Circular No. A-94 Revised, http://www.whitehouse.gov/omb/circulars_a094).

Multimodal Analysis

The HERS, TERM, and NBIAS all use consistent valuations of travel time savings and of reductions in transportation injuries and fatalities, which are key variables in any economic analysis of transportation investment. Although HERS, TERM, and NBIAS all use benefit-cost analysis, their methods for implementing this analysis differ significantly. The highway, transit, and bridge models each rely on separate databases, making use of the specific data available for each mode of the transportation system and addressing issues unique to that mode.

These three models have not yet evolved to the point where direct multimodal analysis would be possible. For example, HERS assumes that, when lanes are added to a highway, highway user costs will initially fall, resulting in additional highway travel. Some of the increased use of the expanded facility would result from newly generated travel, while some would be the result of travel shifting from transit to highways. However, HERS is unable to distinguish between these different sources of additional highway travel. At present, the models provide no direct way to analyze the impact that a given level of highway investment in a particular location would have on the transit investment in that vicinity (or vice versa). Opportunities for future development of HERS, TERM, and NBIAS, including efforts to allow feedback between the models, are discussed in Appendix D.

Uncertainty in Transportation Investment Modeling

The three investment analysis models used in this report are deterministic rather than probabilistic, meaning that they provide a single projected value of total investment for a given scenario rather than a range of likely values. As a result, it is possible to make only general statements about the element of uncertainty in these projections, based on the characteristics of the process used to develop them, rather than giving specific information about confidence intervals. As was indicated above, the analysis in Chapter 10 of this edition of the C&P report enables statements about the sensitivity of the scenario projections to variation in the underlying parameters (e.g., discount rates, value of time saved, statistical value of lives saved, etc.). As far as possible, the range of variation considered in these tests corresponds to the range considered plausible in the corresponding research literature or to ranges recommended in authoritative guidance. The sensitivity tests address only some of the elements of uncertainty in the scenario projections. In some cases, the uncertainty goes beyond the value of a model parameter to the entire specification of the equations in which the parameters are embedded.

The modeling undertaken for the C&P report is simplified by omitting certain effects. These are effects for which reliable quantification is either unfeasible or would require a modeling or data collection effort out of proportion with their likely significance. In particular, while the modeling uses benefit-cost analysis to evaluate potential investments in transportation infrastructure, some external costs and benefits are omitted.

The omissions include, for example, costs or benefits from impacts on noise pollution and benefits from increased competition when transportation investments improve access to markets. Across a broad program of investment projects, such external effects may fully or partially cancel each other out; to the extent that they do not, the "true" level of investment required to achieve a particular goal may be either higher or lower than those predicted by the model. Some projects that HERS, TERM, or NBIAS view as economically justifiable may not be after more careful scrutiny, while other projects that the models would reject might actually be justifiable if these other factors were considered.

There are differences in the relative level of uncertainty among different projections made in this report. As already noted, the projections for all roads system-wide are less reliable than those for Federal-aid highways. In addition, the projections for absolute levels of conditions and performance indicators entail more uncertainty than the differences among these levels according to an assumed level of investment. For example, if speed limits were increased nationwide in the future, contrary to the HERS modeling assumption of no change from the base-year speed limits, this might significantly reduce the accuracy of the model's projections for average speed. At the same time, the indications based on these projections of how the amount of future investments in highways affects average speed could be relatively accurate. Although investments in highway capacity expansion increase average speed, the increase will occur mainly under conditions of congestion when average speeds can be well below even the current speed limit. Under such conditions, an increase in the speed limit may have a negligible effect on the congestion reduction benefits from adding lanes.

CHAPTER 7

Potential Capital Investment Impacts

Potential Highway Capital Investment Impacts

The analyses presented in this section use a common set of assumptions to derive relationships between alternative levels of future highway capital investment and various measures of future highway and bridge conditions and performance. A subsequent section within this chapter provides comparable information for different types of potential future transit investments.

The analyses in this section focus on the types of investment within the scopes of the Highway Economic Requirements System (HERS) and the National Bridge Investment Analysis System (NBIAS), and form the building blocks for the capital investment scenarios presented in Chapter 8. The accuracy of the projections in this chapter depends on the validity of the technical assumptions underlying the analysis, some of which are varied in the sensitivity analysis in Chapter 10. The analyses presented in this section do not make any explicit assumptions regarding how future investment in highways might be funded.

Types of Capital Spending Projected by HERS and NBIAS

The types of investments evaluated by HERS and NBIAS can be related to the system of highway functional classification introduced in Chapter 2 and to the broad categories of capital improvements introduced in Chapter 6 (system rehabilitation, system expansion, and system enhancement). NBIAS relies on the NBI database, which covers bridges on all highway functional classes, and evaluates improvements that generally fall within the system rehabilitation category.

HERS evaluates pavement improvements—resurfacing or reconstruction—and highway widening; the types of improvements included in these categories roughly correspond to system rehabilitation and system expansion as described in Chapter 6. In estimating the per-mile costs of widening improvements, HERS recognizes a typical number of bridges and other structures that would need modification. Thus, the estimates from HERS are considered to represent system expansion costs for both highways and bridges. Coverage of the HERS analysis is limited, however, to Federal-aid highways, as the Highway Performance Monitoring System (HPMS) sample does not include data for rural minor collectors, rural local roads, or urban local roads.

The term "non-modeled spending" refers in this report to spending on highway and bridge capital improvements not evaluated in HERS or NBIAS; while these types of spending are absent from the analyses presented in this chapter, the capital investment scenarios presented in Chapter 8 are adjusted to account for them. Non-modeled spending includes capital improvements on highway classes omitted from the HPMS sample and hence the HERS model. Development of future investment scenarios for the highway system as a whole thus requires separate estimation outside the HERS modeling process.

Non-modeled spending also includes types of capital expenditures classified in Chapter 6 as system enhancements, which neither HERS nor NBIAS currently evaluate. Although HERS incorporates assumptions about future operations investments, whose capital components would be classified as system enhancements, the model does not directly evaluate the need for these deployments. In addition, HERS does not identify specific safety-oriented investment opportunities, but instead considers the ancillary safety impacts of capital investments that are directed primarily toward system rehabilitation or capacity expansion. This limitation of the model owes to the HPMS database containing no information on the location of crashes or of safety devices such as guardrails or rumble strips.

Q&A

How closely do the types of capital improvements modeled in HERS and NBIAS correspond to the specific capital improvement type categories presented in Chapter 6?

Exhibit 6-12 in Chapter 6 provides a crosswalk between a series of specific capital improvement types for which data are routinely collected from the States, and three major summary categories: system rehabilitation, system expansion, and system enhancement. The types of improvements covered by the HERS and NBIAS model are assumed to correspond with the system rehabilitation and system expansion categories. As in *Exhibit 6-12*, HERS splits spending on "reconstruction with added capacity" between these categories.

The assumed correspondence is close overall, but for some of the detailed categories in *Exhibit 6-12* not exact. In particular, the extent to which HERS covers construction of new roads and bridges is ambiguous. While not directly modeled in HERS, such investments are often motivated by a desire to alleviate congestion on existing facilities in a corridor, and thus would be captured indirectly by the HERS analysis in the form of additional normal-cost or high-cost lanes. As described in Appendix A, the costs per mile assumed in HERS for high-cost lanes are based on typical costs of tunneling, double-decking, or building parallel routes, depending on the functional class and area population size for the section being analyzed. To the extent that investments in the "new construction" and "new bridge" improvement types identified in Chapter 6 are motivated by desires to encourage economic development or accomplish other goals aside from the reduction of congestion on the existing highway network, such investments would not be captured in the HERS analysis.

Some other comparability issues include:

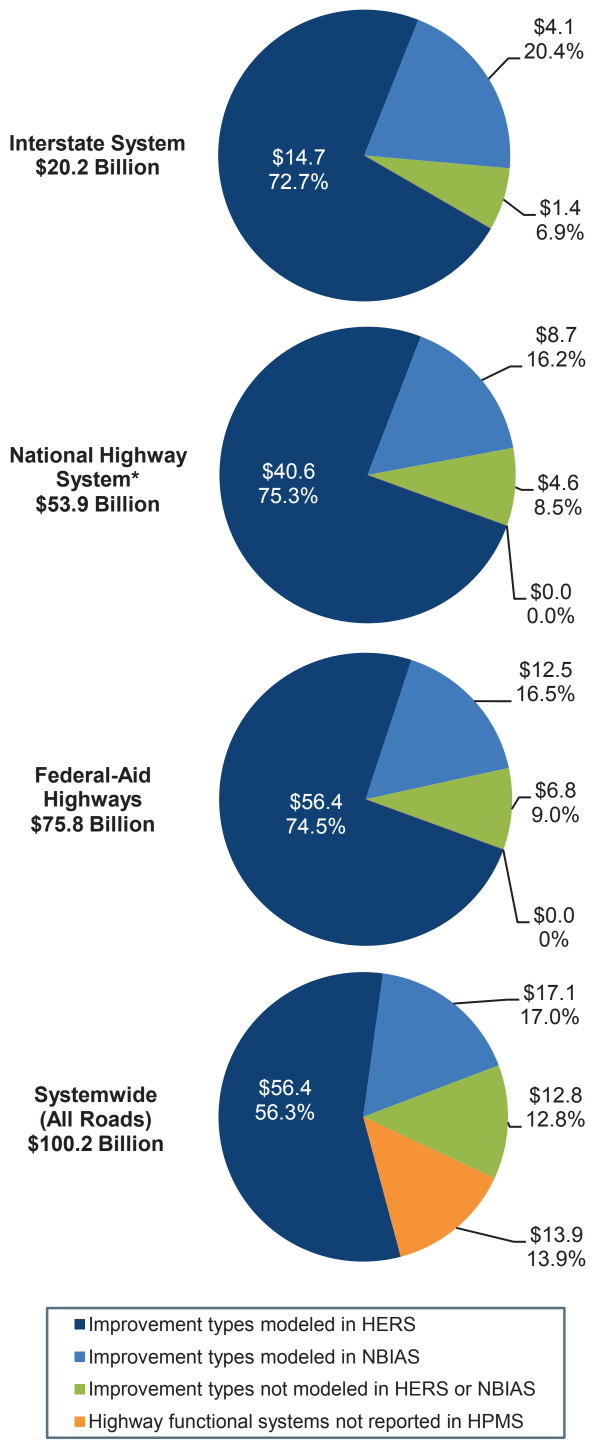
- HERS captures relocation improvements that are components of system expansion projects to relieve congestion, but may not capture relocation improvements that are motivated more by safety concerns.
- The bridge expenditures that *Exhibit 6-12* counts as system rehabilitation may include work on bridge approaches and ancillary improvements that are not modeled by NBIAS.
- HERS and NBIAS are assumed not to capture improvements that count as system enhancement spending, including the spending on the "safety" category in *Exhibit 6-12*. However, some safety deficiencies may be addressed as part of broader pavement and capacity improvements modeled in HERS.
- The HERS Operations preprocessor described in Appendix A includes capital investments in operations equipment and technology that would fall under the definition of the "traffic management/engineering" improvement type in Chapter 6. These investments are counted among the non-modeled system enhancements because they are not evaluated within the benefit-cost framework that HERS applies to system preservation and expansion investments.

Exhibit 7-1 shows that systemwide in 2010, highway capital spending amounted to $100.2 billion, of which $56.4 billion went for types of improvements modeled in HERS and $17.1 billion for types of improvement modeled in NBIAS. The other $26.7 billion that went for non-modeled highway capital spending was divided fairly evenly between system enhancement expenditures and capital improvements to classes of highways not reported in HPMS.

Because the HPMS sample data are available only for Federal-aid highways, the percentage of capital improvements classified as non-modeled spending is lower for Federal-aid highways than is the case systemwide. Of the $75.8 billion spent by all levels of government on capital improvements to Federal-aid highways in 2010, 74.5 percent fell within the scope of HERS, 16.5 percent fell within the scope of NBIAS, and 9.0 percent was for spending captured by neither model. The percent distribution is similar for the Interstate Highway System.

It should be noted that the statistics presented in this chapter and Chapter 8 relating to future National Highway System (NHS) investment are based on an estimate of what the NHS will look like after it is expanded pursuant to MAP-21, rather than the system as it existed in 2010. As indicated in Chapter 6, combined highway capital spending by all levels of government on the NHS in 2010 totaled $44.4 billion.

Exhibit 7-1 **Distribution of 2010 Capital Expenditures by Investment Type (Billions of Dollars)**



*The NHS statistics presented in this chapter are intended to approximate the NHS as it will exist after its expansion directed by MAP-21, not the NHS as it existed in 2010.

Source: Highway Statistics 2010, Table SF-12A, and unpublished FHWA data.

The $53.9 billion NHS spending figure referenced in *Exhibit 7-1* includes amounts spent on other principal arterials, as much of this mileage will be added to the NHS.

Treatment of the NHS in 20-Year Projections

Pursuant to MAP-21, the NHS will be expanded to include additional principal arterial and connector mileage that was not part of the original system. In light of this change, projecting future NHS investment needs over 20 years based on the system as it existed in 2010 would not produce particularly useful results.

Rather than dropping the NHS projections from the C&P report series until such time as the system as the formal NHS re-designation is completed, this report includes projections based on an estimate of what the system would ultimately look like, by adding in principal arterials that are not currently part of the NHS.

Once the revised NHS designations have been coded into the HPMS and NBI, future editions of this report will use them for all NHS-based analyses.

Alternative Levels of Future Capital Investment Analyzed

The HERS and NBIAS analyses presented in this chapter each assumes that capital investment within the scope of the model will grow over the 20 years at a constant annual percentage rate, which could be positive, negative, or zero. The starting point for each analysis is the level of investment in 2010, which includes one-time funding under the American Recovery and Reinvestment Act of 2009 (Recovery Act). Because future levels are measured in constant 2010 dollars, the percent rates of growth are real (inflation-adjusted). This "ramped" approach to analyzing alternative investment levels was introduced in the 2008 C&P Report. Previous editions had either assumed a fixed amount would be spent in each year or set funding levels based on benefit-cost ratios, which tended to front-load the investment within the 20-year analysis period. Chapter 9 includes an analysis of the impacts on conditions and performance of these alternative investment timing patterns, as well as an example of how the ramping approach impacts year-by-year funding levels for some of the highway investment scenarios presented in Chapter 8.

This chapter provides a quantitative picture of potential highway and bridge system outcomes under alternative assumptions about the rate of ramped investment growth. The particular investment levels identified were selected from among the results of a much larger number of model simulations. **Each investment level shown corresponds to a particular target outcome, such as funding all potential capital improvements with a benefit-cost ratio above a certain threshold or attaining a certain performance standard for highways or bridges.** While each of the particular rates of change selected has some specific analytical significance, the analyses presented in this chapter do not constitute complete investment scenarios, but rather form the building blocks for such scenarios, which are presented in Chapter 8.

Highway Economic Requirements System

Simulations conducted with the HERS model provide the basis for this report's analysis of investment in highway resurfacing and reconstruction as well as for highway and bridge capacity expansion. HERS employs incremental benefit-cost analysis to evaluate highway improvements based on data from the HPMS. The HPMS includes State-supplied information on current roadway characteristics, conditions, and performance and anticipated future travel growth for a nationwide sample of more than 120,000 highway sections. HERS analyzes individual sample sections only as a step toward providing results at the national level; the model does not provide definitive improvement recommendations for individual sections.

Simulations with the HERS model start by evaluating the current state of the highway system using data from the HPMS sample. These data provide information on pavements, roadway geometry, traffic volume and composition (percent trucks), and other characteristics of the sampled highway sections. For sections with one or more deficiencies identified, the model then considers potential improvements, including resurfacing, reconstruction, alignment improvements, and widening or adding travel lanes. HERS selects the improvement (or combination of improvements) with the greatest net benefits, where benefits are defined as reductions in direct highway user costs, agency costs for road maintenance, and societal costs from vehicle emissions of greenhouse gases and other pollutants. (The model uses estimates of emission costs that include damage to property and human health and, in the case of greenhouse gases, certain other potential impacts such as loss of outdoor recreation amenities.) The model allocates investment funding only to the sections where at least one of the potential improvements are projected to produce benefits exceeding construction costs.

Q&A

How closely does the HERS model simulate the actual project selection processes of State and local highway agencies?

While the HERS model is a powerful tool for projecting future investment/performance relationships, the process of project selection in the model differs from reality in several respects. HERS assumes that the allocation of total national spending on highway investment will be "economically efficient," meaning that the projects selected will be the set that maximizes total benefits to society. The model takes no account of the division of funding authority among States and localities. For example, it could program a large increase in highway investment in a State that lacks the needed budgetary resources. The model does not attempt to simulate the influence on project selection decisions of evaluation criteria other than economic efficiency, such as perceptions of fairness and political considerations. To the extent that these other factors shape the project selection decisions, HERS may underestimate the level of investment needed to achieve a given performance or conditions target, such as maintaining average pavement ride quality.

In addition, HERS lacks access to the full array of information that governments would need to determine what is economically efficient. It relies on the HPMS database, which provides only a limited amount of information on each sampled highway section. For example, while the HPMS includes information regarding the potential for adding lanes to each highway section, and obstacles to further widening, it does not currently include information on the feasibility of alternative approaches to added capacity in a given location (construction of parallel routes, double-decking, tunneling, investments in other transportation modes, etc.). This issue is discussed further in Appendix A.

HERS normally considers highway conditions and performance over a period of 20 years from the base ("current") year, which is the most recent year for which HPMS data are available. This analysis period is split into four funding periods of equal length. After HERS performs its analysis for the first funding period, it updates the database to reflect the influences of what is predicted to happen during the first period, including the effects of the selected highway improvements. The updated database is the foundation for the analysis of conditions and performance in the second period, and so on through the fourth and last period. Appendix A contains a more detailed description of the project selection and implementation process used by HERS.

HPMS Database

The analyses presented in the 2010 C&P report relied on the 2008 HPMS database. The HPMS has subsequently been significantly modified, incorporating major changes in database structure and data items. These changes emerged from a comprehensive reassessment of how well the database was meeting user and customer needs; for details, see *the HPMS Reassessment 2010+ Final Report* issued in September 2008.

Changes to the HPMS

The new HPMS structure organizes data into program areas and links them together through a Geographic Information System (GIS) using spatial relationships. The revised procedures include those for creating the statistical population of highway sections from which the HPMS sample is drawn (to better ensure homogeneity over each section's length with respect to traffic volume, number of through lanes, and other key variables) and those for averaging or summarizing measures from which different values have been estimated over a section's length (e.g., for pavement roughness). A number of new data items have been added to the HPMS, particularly in regards to pavement characteristics and different types of pavement distresses, which are intended to support more robust analysis of pavement performance in HERS. Another key change from the HERS perspective was the replacement of an old data item regarding widening feasibility with two new items intended to provide more specific information on widening potential in terms of the specific number of lanes that could be added to a given location and obstacles to further widening; these data items are intended to support more robust analysis of widening alternatives. Appendix D discusses possible enhancements to HERS to make use of new data items on highway ramps and on measures of pavement distress other than pavement roughness.

Assessment of 2010 HPMS Sample Database's Suitability for HERS

With the data requirements for the C&P report in mind, the initial timetable for the HPMS reassessment implementation called for States to start submitting data in the new format for the 2009 data year, in the hopes that any problems with the changeover could be addressed and resolved in time for the 2010 data submittal. However, the timetable was delayed, and only 15 States reported using the new HPMS format in 2009; for most States, 2010 was the first year in which they submitted data items under the new format.

The initial Federal Highway Administration (FHWA) data reviews conducted on the 2010 HPMS data focused on addressing issues pertaining to the types of statistics on current system characteristics and system conditions that are presented in Chapters 2 and 3. While these national-level data are considered reasonably reliable, subsequent examination of the more detailed HPMS sample data identified a large number of omissions and seemingly implausible coding for some individual items and for some combinations of data reported in different fields. Of particular concern were the large numbers of:

- Blank entries for both the International Roughness Index (IRI) and Present Serviceability Rating (PSR)
- Blank entries for pavement surface type or inconsistent entries relative to what is coded in other fields
- Miscoded responses for widening potential (at most, 20 States coded the field correctly)
- Seemingly implausible entries for the numbers of peak, counterpeak, and total lanes relative to each other
- Missing entries for single unit and combination truck traffic.

The data omissions in particular present a problem for the HERS model, which relies on having a completely populated sample data set for each individual sample record that it analyzes. In order to make use of the 2010 HPMS data, a significant effort was undertaken to impute logical values for some of the omitted data, and to develop additional screens to adjust apparent data outliers. Based on these procedures, a modified data set was then tested in HERS. This testing found anomalies in the pavement performance analysis; this was not wholly unexpected, as this was the first full national-level test of both new pavement data items and new pavement performance models that had been introduced into HERS to take advantage of these data. More puzzling were anomalies in the operational performance analysis, as these aspects of HERS had not been significantly modified, so that the changes in results could be attributed solely to the HPMS data.

In light of these issues, the FHWA has determined that for the purposes of this report, the 2008 HPMS sample data would serve as a better proxy for the "current" conditions and performance of the highway system than would the 2010 HPMS sample data set in its present form. Based on this decision, the analyses presented in this report have been developed using an older version of HERS very similar to that used for the 2010 C&P report, rather than utilizing the newer version of HERS that is customized for use with the new HPMS data format.

The FHWA will be working with the States to address issues with the HPMS sample data reporting to improve its utility for supporting future editions of the C&P report. As States become more familiar with the new HPMS data structure and data fields over time, the completeness and quality of the data should improve. To the extent that the modified HPMS structure facilitates the reporting of better data, some degree of inconsistency with the data reported in previous years can be expected.

Implications of Database Selection

Although this edition uses the same 2008 HPMS database as was used in the 2010 C&P report, other input variables were updated from 2008 to 2010, resulting in significantly different projections than those presented in the 2010 C&P report. Base-year values were updated to 2010 for prices and unit costs, average vehicle fuel efficiency, vehicle emission rates, and the level on highway investment (for runs that assume highway investment to remain at the base-year level in constant dollars). Inputs in the form of projections for fuel efficiency and vehicle emissions rates were updated to the analysis period used throughout Part II of this report, 2011-2030.

On the basis of these updates, this report considers the base year for the HERS analyses to be 2010 and the projection period to be the subsequent two decades through 2030. However, the reliance on the 2008 HPMS database should be borne in mind when interpreting the exhibits in this and following chapters. Except as noted, the base year values reported for conditions and performance indicators are actually HERS-computed values for 2008 serving as proxies for 2010 values.

Operations Strategies

Starting with the 2004 C&P report, the HERS model has considered the impacts of certain types of highway operational improvements, in which intelligent transportation systems (ITS) feature prominently. The types of strategies currently evaluated by HERS include:

- Freeway management (ramp metering, electronic roadway monitoring, variable message signs, integrated corridor management, variable speed limits, queue warning systems, lane controls)
- Incident management (incident detection, verification, and response)
- Arterial management (upgraded signal control, electronic monitoring, variable message signs)
- Traveler information (511 systems and advanced in-vehicle navigation systems with real-time traveler information).

Appendix A describes these strategies in more detail and their treatment in the HERS model. It is important to note that HERS does not subject these types of investments to benefit-cost analysis and does not directly analyze tradeoffs between them and the pavement improvements and widening options also considered by the model. Instead, operations strategies are modeled via a separate preprocessor that estimates their impact on the performance of highway sections where they are deployed. The analyses presented in this chapter assume a package of investments representing the continuation of existing deployment trends, while a sensitivity analysis presented in Chapter 10 considers the impacts of a more aggressive deployment pattern. HERS does not currently model various applications of vehicle-to-vehicle and vehicle-to-infrastructure communications that are under development because it is too early to reliably predict their impacts and patterns of deployment.

Q&A

How will Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications potentially impact future investment needs?

Cellular, Wi-Fi, and other dedicated short-range communication technologies are expanding the possibilities for a Connected Vehicle Environment. Communications among vehicles on the road (V2V), and between these vehicles and infrastructure (V2I) hold promise for substantial reductions in crashes and vehicle emissions, and enhanced mobility through more efficient transportation systems management and operations. Adding to this potential are rapid advances in vehicle automation. For example, under advanced speed harmonization, vehicle speed would adjust automatically to speed limits that vary based on road, traffic, and weather conditions (an existing V2I application).

Additional examples of connectivity applications include blind spot monitoring/lane change warning, smart parking, forward collision warning, do-not-pass warning, curve speed warning, red light violation warning, transit pedestrian warning, cooperative adaptive cruise control, breaking assist, and dynamic lane closure management.

To reach the full potential of connected vehicles will require investment, coordination, and partnership with public and private entities. As development and implementation of connected vehicle applications proceeds, additional information should make possible their representation in HERS. Research efforts by FHWA, FTA, NHTSA, AASHTO and others that will measure benefits and costs of these applications include: (1) Applications for the Environment: Real-Time Information Synthesis (AERIS) Program; (2) AASHTO Connected Vehicle Field Infrastructure Footprint Analysis; (3) Connected and Automated Vehicle Benefit Cost Analysis; and (4) Measuring Local, Regional and Statewide Economic Development Associated with the Connected Vehicle program.

HERS Treatment of Traffic Growth

For each HPMS sample highway section, States provide the actual traffic volume in the base year and a forecast of traffic volume for a future year, based on available information concerning the particular section and the corridor of which it is a part. These forecasts are interpreted by HERS as having been made under the assumption that the average user cost per mile of travel, including costs of travel time, vehicle operation, and crash risk, would remain unchanged over the 20-year analysis period.

Because the present HERS analysis uses the HPMS sample data for 2008, the traffic volumes for the base and forecast years pertain to 2008 and 2028. In the 2008 database, the composite weighted average annual VMT growth rate between the 2008 base year and the forecast year is 1.85 percent. Projected VMT growth in rural areas averages 2.15 percent per year, somewhat higher than the average of 1.70 percent in urban areas.

To allow for the possibility that future traffic growth will be lower than forecast in the HPMS, the HERS analysis presented in this report considers an alternative in which VMT grows at the trend rate of 1.36 percent per annum that prevailed from 1985 to 2010. In this case, the section-level forecasts of VMT from the HPMS are reduced in uniform proportion to bring the growth rate of VMT down to this level from the 1.85 percent assumed in the baseline. *Exhibit 7-2* applies the alternative forecast growth rates,

1.36 percent and 1.85 percent, to actual Federal-aid highway and systemwide VMT for 2010 to derive year-by-year estimates through 2030. An underlying assumption is that VMT will grow in a linear fashion (so that 1/20th of the additional VMT is added each year), rather than geometrically (growing at a constant annual rate). With linear growth, the annual percent rate of growth gradually declines over the forecast period.

What are some of the technical limitations associated with the analysis of alternative trend-based travel growth rates included in this section?

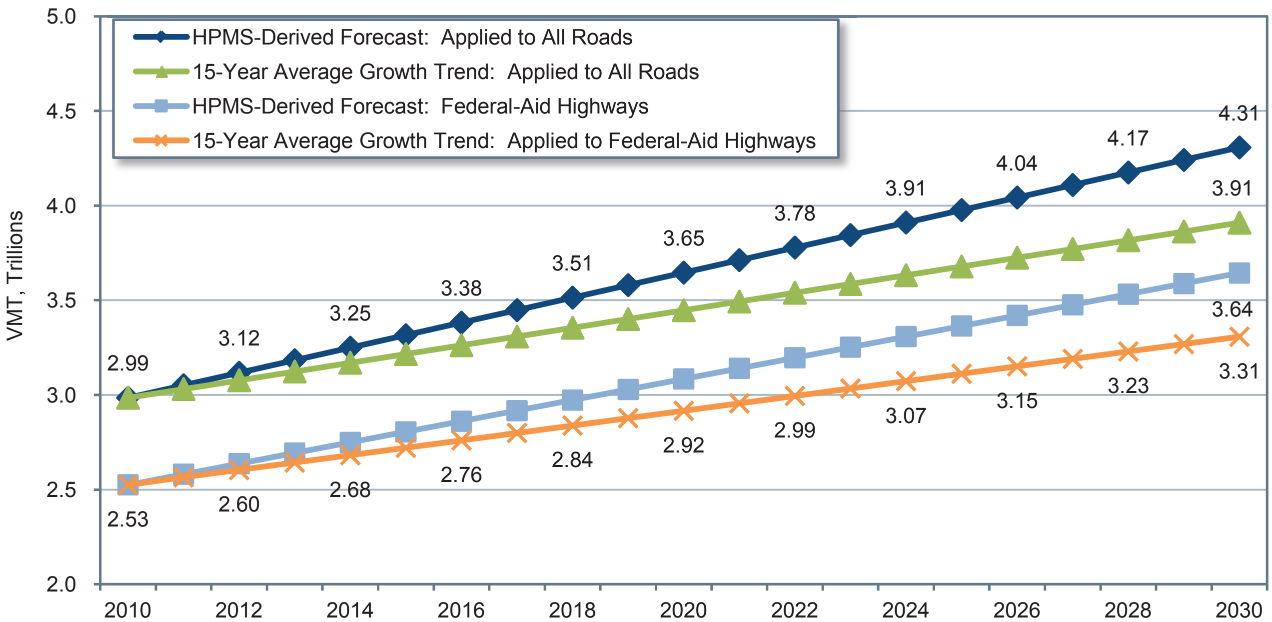
Q&A

One of the strengths of the State-provided VMT forecasts used in the baseline analysis is their geographic specificity. Separate forecasts are provided for the more than 100,000 HPMS sample sections. The **1.85 percent** average annual VMT growth rate referenced as the "**forecast VMT growth**" in this section reflects a compilation of these forecasts for individual sample sections.

In forming their section-specific forecasts, States can take account of specific local influences on travel growth and their own long-range planning assumptions about future travel patterns on particular routes or corridors. The inclusion of these section-level forecasts, as opposed to regional or statewide travel estimates, allows for more refined analyses of projected future investment/performance relationships.

The analyses based on the alternative "**trend VMT growth**", adjust the HPMS-derived forecasts for the next 20 years to match the 15-year trend from 1995 to 2010 when average VMT increased at an average annual rate of **1.36 percent**. These analyses use a top-down, rather than a bottom-up approach; while they use the HPMS forecasts for individual highway sections as a starting point, these forecasts are adjusted downward in uniform proportion on a national basis. In reality, if VMT were to grow more slowly than the State projections, these differences would not be uniform, and could be heavily concentrated in particular corridors, regions, or States. Moreover, these differences could significantly impact the level of investment that might be required to achieve particular systemwide performance targets. The assumption of uniformity thus limits the reliability of this section's analysis of the trend-based alternative VMT growth rates.

Exhibit 7-2 Annual Projected Highway VMT Based on HPMS Forecasts or Actual 15-Year Average Growth Trend



Note: The HPMS forecasts were for the period 2008 to 2028, but their average annual growth rates have been applied to actual 2010 VMT and extended to 2030 for purposes of this analysis. The alternative forecast substitutes in the actual average annual VMT growth trend from 1995 to 2010 and extends it through 2030.

Source: Highway Performance Monitoring System.

Travel Demand Elasticity

One of the key features of the economic analysis in HERS is the influence of the cost of travel on the demand for travel. HERS represents this relationship as a travel demand elasticity that relates demand, measured by VMT, to average user cost per VMT. The model applies this elasticity to the forecasts of future travel (VMT) found in the HPMS sample data, which are interpreted as constant user cost forecasts. Any change that HERS projects in user cost relative to the base-year level will, through the mechanism of the travel demand elasticity, affect the model's projection for future travel growth. For any highway investment scenario that predicts average user cost to decrease, the projected growth rate will be higher than the baseline rate derived from HPMS. The demand for travel induced by the reduction in cost could arise from various traveler responses in various ways—for example, changing route or mode of travel, or even the total amount of travel undertaken. Conversely, for scenarios in which highway user cost increases, the projected VMT growth rate will tend to be lower than the baseline rate.

HERS also allows the induced demand predicted through the elasticity mechanism to influence the cost of travel to highway users. On congested sections of highway, the initial congestion relief afforded by an increase in capacity will reduce the average user cost per VMT, which in turn will stimulate demand for travel and this increased demand will reverse a portion of the initial congestion relief. The elasticity feature operates likewise with respect to improvements in pavement quality by allowing for induced traffic that adds to pavement wear. (Conversely, an initial increase in user costs can start a causal chain with effects in the opposite direction). By capturing these offsets to initial impacts on highway user costs, HERS is able to estimate the net impacts.

Impacts of Federal-Aid Highway Investments Modeled by HERS

The present HERS analysis starts with an evaluation of the state of Federal-aid highways in the 2010 base year. *Exhibit 7-1* showed that capital spending on these highways for the types of improvements modeled in HERS then amounted to $56.4 billion (out of total highway capital spending of $100.2 billion). The analysis next goes on to consider the potential impacts on system performance of raising or lowering the amount of investment within the scope of HERS at various annual rates over 20 years. Spending in any year is measured in constant 2010 dollars, so that spending and its rate of growth are both measured in real rather than nominal terms. Chapter 9 includes an illustration of how future spending levels could be converted from real to nominal dollars levels under alternative assumptions about the future inflation rate.

Selection of Investment Levels for Analysis

Exhibit 7-3 describes the significance of the 10 funding levels selected for presentation in this chapter. Some of these funding levels over the 20-year analysis period are geared toward the attainment of a specific minimum value over that period for the benefit-cost ratio (BCR). As explained in the introduction to Part II of this report, HERS ranks potential projects in order of BCR and implements them until the funding constraint is reached. The lowest BCR among the projects selected, the "marginal BCR" will vary across the four funding periods, and HERS refers to the lowest of these values across the funding periods as the "minimum BCR". For each minimum BCR target, 1.0 or 1.5, the requisite amount of investment is determined under the alternative baseline assumptions about the future growth rate of VMT: the HPMS forecast rate (1.85 percent per annum) or the historical trend rate (1.36 percent per annum). The highest level of spending shown in *Exhibit 7-3* corresponds to the annual growth rate in real spending, 3.95 percent, associated with a minimum BCR of 1.0 in the forecast VMT growth case. The attainment of this minimum BCR can be interpreted as having implemented all potentially cost-beneficial projects (BCR≥1.0). The next highest level of spending shown in *Exhibit 7-3* is the estimate of what would achieve this target assuming

trend-based VMT growth and averages $70.5 billion per year, which is about 18 percent less than in the forecast-based VMT growth case ($86.9 billion per year).

Other funding levels shown in *Exhibit 7-3* are geared toward achieving a specific level of performance for a particular indicator for 2030—average congestion delay per VMT, average speed, or the average IRI. For each such indicator, the requisite amount of investment to maintain the base-year level is shown for the forecast-based VMT growth case. Shown for the cases of both forecast-based and trend-based VMT, growth is the "Cost to Maintain," which is the average of the investment levels associated with maintaining the congestion delay and pavement roughness indicators. (Separate values are not shown for the investment levels associated with maintaining average delay per VMT and maintaining average IRI in the trend-based VMT growth case, as coincidentally they are virtually identical). In the trend-based VMT growth case, this level of investment averages $35.7 billion per year, the lowest amount shown in *Exhibit 7-3*, and associated rate with negative 4.3-percent annual growth in investment. (The connections between funding growth rates and performance indicators are identifiable from the exhibits presented later in this section).

The other rate of investment growth in *Exhibit 7-3* is zero, for the case where average annual spending over 2010–2030 remains at the actual level of spending in 2010 in constant dollar terms.

Exhibit 7-3 Description of Ten Alternative HERS-Modeled Investment Levels Selected for Further Analysis

HERS-Modeled Capital Investment		Minimum BCR [2]		
Annual Percent Change in Spending	Average Annual Spending [1] (Billions of 2010 Dollars)	Assuming Forecast VMT Growth [3]	Assuming Trend VMT Growth [4]	Funding Level Description Assuming Future VMT Growth Consistent With HPMS Forecast ("Forecast") or Consistent with VMT Growth Trend "(Trend)"
3.95%	$86.9	1.00	–	Minimum BCR=1.0 (Forecast)
2.08%	$70.5	1.42	1.00	Minimum BCR=1.0 (Trend)
1.71%	$67.8	1.50	1.06	Minimum BCR=1.5 (Forecast)
0.72%	$60.9	1.73	1.27	Average Delay per VMT in 2030 Matches 2010 Level (Forecast)
0.00%	$56.4	1.92	1.42	Constant Dollar Investment Sustained at 2010 Level
-0.32%	$54.6	2.01	1.50	Minimum BCR=1.5 (Trend)
-0.66%	$52.7	2.09	1.58	Average Speed in 2030 Matches 2010 Level (Forecast)
-0.95%	$51.1	2.17	1.64	"Cost to Maintain" (Forecast) [5]
-2.62%	$43.2	2.64	2.08	Average IRI in 2030 Matches 2010 Level (Forecast)
-4.60%	$35.7	2.83	2.53	"Cost to Maintain" (Trend) [5 6]

[1] The amounts shown represent the average annual investment over 20 years that would occur if annual investment grows in constant dollar terms by the percentage shown in each row of the first column.

[2] The minimum BCR represents the lowest benefit-cost ratio for any project implemented by HERS during the 20-year analysis period at the level of funding shown.

[3] The "Forecast" VMT growth is computed by comparing the current average annual daily traffic (AADT) with the future AADT that are reported by the States for individual HPMS sample sections; nationally this comes out to an average annual growth rate of 1.85% . HERS assumes this represents the VMT that would occur at a constant price (i.e., highway user costs do not increase or decrease), but adjusts the growth for individual sections during its analysis in response to changes in user costs.

[4] The average annual growth rate assumed in the "Trend" VMT growth analyses is 1.36%, matching the average growth rate for the 15-year period from 1995 to 2010. To implement this assumption, the future AADT values reported for each HPMS sample section in HPMS were proportionally reduced; the resulting values were assumed to be the VMT that would occur at a constant price.

[5] The "Cost to Maintain" represents the average of the investment levels associated with maintaining average delay per VMT and maintaining IRI, and is used in the "Maintain Conditions and Performance" investment scenarios in Chapter 8.

[6] Assuming VMT growth follows its 15-Year Trend, the annual percent change in spending at which average delay per VMT in 2030 matches the 2010 level is negative 4.61 percent, while the annual rate of spending change at which average IRI in 2030 matches the 2010 level is negative 4.60 percent. Since these values are so close, their investment levels are not identified separately, and the "Cost to Maintain" is defined around an annual change of negative 4.60 percent.

Source: Highway Economic Requirements System.

Why are many of the spending growth rates associated with meeting performance targets negative in this report, when they were positive in the 2010 C&P report?

Q&A

Actual highway capital investment for capital improvements modeled in HERS rose from $54.7 billion in 2008 (base year for the 2010 C&P report) to $56.4 billion in 2010, a 3 percent increase in nominal dollar terms. However, this coincided with a steep drop in highway construction costs, estimated in this report to have been about 18 percent. Factoring in this price change, real spending within the scope of HERS is estimated to have increased between 2008 and 2010 by almost 26 percent. This does much to explain why the present analysis indicates that maintaining target performance indicators at their base-year levels would be consistent with spending less than in the base year, whereas the analysis presented in the 2010 C&P report indicated that spending more than in the base year would be required.

It should also be noted that 2010 highway capital investment was supplemented by one-time funding under the Recovery Act, which would make it more challenging to sustain this level of investment in the future.

Investment Levels and BCRs by Funding Period

Exhibit 7-4 illustrates how the 10 alternative funding growth rates for Federal-aid highways that were selected for further analysis in this chapter would translate into cumulative spending in 5-year intervals

Exhibit 7-4 Benefit-Cost Ratio Cutoff Points Associated With Different Possible Funding Levels for Federal-Aid Highways

Annual Percent Change in HERS Capital Spending	Spending Modeled in HERS (Billions of 2010 Dollars): Cumulative					Spending Modeled in HERS (Billions of 2010 Dollars): Average Annual Spending Over 20 Years[1]	Marginal BCR[2]				Minimum BCR
	5-Year 2011 to 2015	5-Year 2016 to 2020	5-Year 2021 to 2025	5-Year 2026 to 2030	20-Year 2011 to 2030		5-Year 2011 to 2015	5-Year 2016 to 2020	5-Year 2021 to 2025	5-Year 2026 to 2030	20-Year 2011 to 2030
Assuming Forecast VMT Growth											
3.95%	$317	$385	$468	$568	$1,738	$86.9	2.30	1.73	1.30	**1.00**	1.00
2.08%	$300	$333	$369	$409	$1,411	$70.5	2.40	1.97	1.63	**1.42**	1.42
1.71%	$297	$323	$352	$383	$1,355	$67.8	2.42	2.03	1.70	**1.50**	1.50
0.72%	$288	$299	$310	$321	$1,218	$60.9	2.47	2.17	1.89	**1.73**	1.73
0.00%	$282	$282	$282	$282	$1,129	**$56.4**	2.51	2.28	2.04	**1.92**	1.92
-0.32%	$279	$275	$271	$266	$1,092	$54.6	2.54	2.33	2.10	**2.01**	2.01
-0.66%	$277	$268	$259	$250	$1,054	$52.7	2.56	2.39	2.17	**2.09**	2.09
-0.95%	$274	$261	$249	$238	$1,023	$51.1	2.58	2.43	2.24	**2.17**	2.17
-2.62%	$261	$228	$200	$175	$864	$43.2	2.68	2.72	**2.64**	2.72	2.64
-4.60%	$246	$194	$153	$121	$714	$35.7	**2.83**	3.12	3.18	3.38	2.83
Assuming Trend VMT Growth											
2.08%	$300	$333	$369	$409	$1,411	$70.5	2.18	1.66	1.22	**1.00**	1.00
1.71%	$297	$323	$352	$383	$1,355	$67.8	2.20	1.71	1.28	**1.06**	1.06
0.72%	$288	$299	$310	$321	$1,218	$60.9	2.27	1.84	1.44	**1.27**	1.27
0.00%	$282	$282	$282	$282	$1,129	**$56.4**	2.32	1.93	1.57	**1.42**	1.42
-0.32%	$279	$275	$271	$266	$1,092	$54.6	2.34	1.98	1.64	**1.50**	1.50
-0.66%	$277	$268	$259	$250	$1,054	$52.7	2.36	2.03	1.70	**1.58**	1.58
-0.95%	$274	$261	$249	$238	$1,023	$51.1	2.38	2.07	1.75	**1.64**	1.64
-2.62%	$261	$228	$200	$175	$864	$43.2	2.49	2.33	2.10	**2.08**	2.08
-4.60%	$246	$194	$153	$121	$714	$35.7	2.62	2.67	**2.53**	2.63	2.53

[1] The amounts shown represent the average annual investment over 20 years that would occur if annual investment grows in constant dollar terms by the percentage shown in each row of the first column.

[2] The marginal BCR represents the lowest benefit-cost ratio for any project implemented during the period identified at the level of funding shown. The minimum BCRs, indicated by bold font and also shown in the last column, are the smallest of the marginal BCRs across the funding periods.

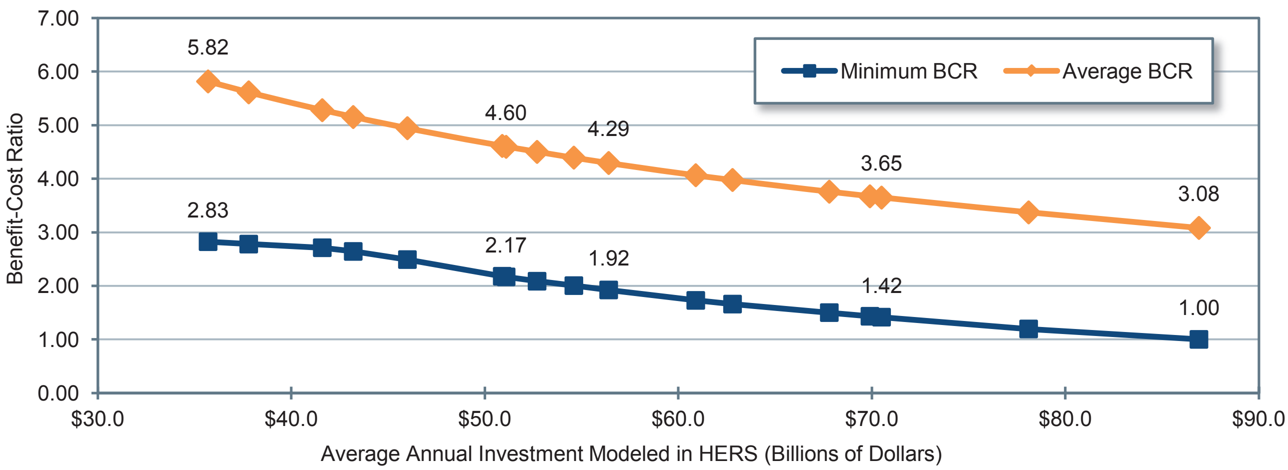
Source: Highway Economic Requirements System.

(corresponding to 5-year analysis periods used in HERS), along with the marginal benefit-cost ratios associated with that investment. The marginal BCR is generally higher for earlier than for later subperiods, resulting in the minimum BCR over the entire analysis period, shown in the last column, equaling the marginal BCR in the last subperiod. This pattern reflects the tendency in HERS for implementing the most worthwhile improvements first. The exception to this pattern occurs when funding is assumed to decline at an annual real rate of negative 2.62 percent or more; in this case, the relative scarcity of funding toward the end of the analysis period limits what can be implemented to relatively high-return projects.

As shown in *Exhibit 7-4*, achieving a minimum BCR of 1.0 is estimated to require $1.738 trillion over the analysis period when forecast VMT growth is assumed and about $1.411 trillion when trend VMT growth is assumed. Applying the more restrictive minimum BCR target of 1.50 would require, respectively, 15 percent and 20 percent less than these amounts ($1.355 trillion and $1.092 trillion over the analysis period).

Further evident in *Exhibits 7-3* and *7-4* is the inverse relationship described in the introduction to Part II between the minimum BCR and the level of investment. *Exhibit 7-5* graphs this inverse relationship, as well as that between the average BCR and the level of investment. At any given level of average annual investment, the average BCR always exceeds the marginal BCR. For example, at the lowest level of investment considered, $714 billion over 20 years, the average BCR of 5.82 exceeds the minimum BCR of 2.83, assume forecast VMT growth.

Exhibit 7-5 Minimum and Average Benefit-Cost Ratios (BCRs) for Different Possible Funding Levels for Federal-Aid Highways



Note: The five minimum BCR points that are labeled correspond to five of the 10 investment levels presented in *Exhibit 7-3*. As HERS ranks potential improvements by their estimated BCRs and assumes that the improvements with the highest BCRs will be implemented first (up until the point where the available budget specified is exhausted), the minimum and average BCRs will naturally tend to decline as the level of investment analyzed rises. The BCRs shown assuming VMT growth consistent with the HPMS-derived forecast.

Source: Highway Economic Requirements System.

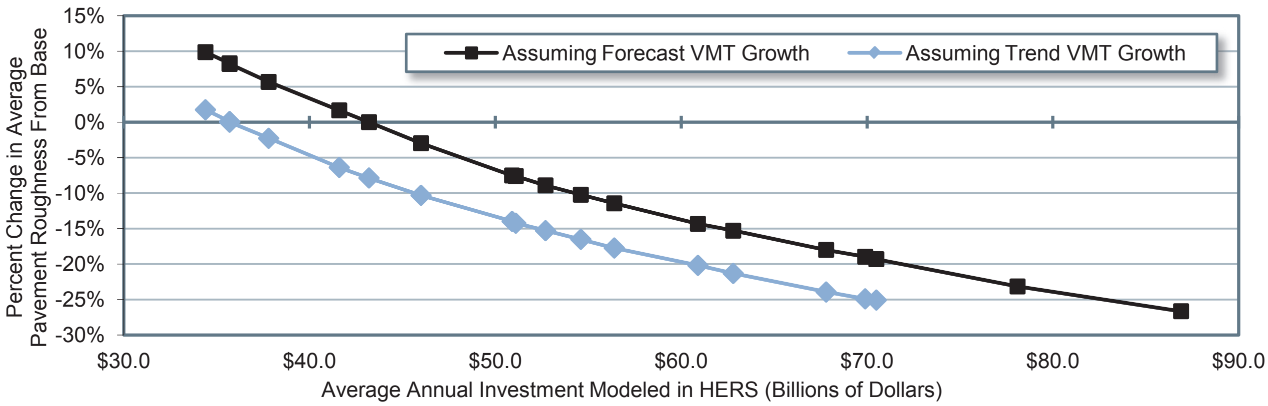
Impact of Future Investment on Highway Pavement Ride Quality

The primary measure in HPMS of highway physical condition is pavement ride quality as measured by the IRI index of pavement roughness (defined in Chapter 3). The HERS analysis presented in this report focuses on VMT-weighted IRI values; the average IRI values shown thus reflect the pavement ride quality experienced on a typical mile of travel. *Exhibit 7-6* shows how the projection for the average IRI on Federal-aid highways in 2030 varies with the total amount of HERS-modeled investment and between the assumptions regarding VMT growth. Also shown is the portion of investment that HERS allocates to system rehabilitation, which is more significant than investment in system expansion in influencing average pavement ride quality.

For each of the funding levels analyzed, HERS would direct a greater share of total spending toward system rehabilitation assuming the trend rate of VMT growth (1.36 percent per annum) rather than the forecast rate of VMT growth (1.85 percent per annum). The lower VMT under the trend growth case also results in less pavement damage from traffic. Consequently, for any given level of investment in Federal-aid highways, *Exhibit 7-6* indicates the average IRI projected for 2030 to be lower in the trend than in the forecast case. For example, assuming that real investment in highways remains at the 2010 base year level of $56.4 billion, the projection is for the average IRI to decline by 17.7 percent to 94.1 in the trend VMT growth case, while it would only decline by 11.5 percent to 101.3 for the forecast VMT growth case.

For almost all combinations of investment level and traffic growth that *Exhibit 7-6* presents, pavements on Federal-aid highways are projected to be smoother on average in 2030 than in 2010. The exception combines spending declining at an average annual rate of 4.6 percent with traffic growing at the forecast

Exhibit 7-6 Projected 2030 Average Pavement Roughness on Federal-Aid Highways Compared with Base Year, for Different Possible Funding Levels



HERS-Modeled Capital Investment				Projected Impacts on Federal-Aid Highways [3]			
Annual Percent Change in Spending	Average Annual Spending (Billions of 2010 Dollars)			Average IRI (VMT-Weighted)			
	Total [1]	System Rehabilitation [2]		Projected 2030 Level		Percent Change Relative to Base Year	
		If Forecast VMT Growth	If Trend VMT Growth	If Forecast VMT Growth	If Trend VMT Growth	If Forecast VMT Growth	If Trend VMT Growth
3.95%	$86.9	$43.9	–	83.9	–	-26.7%	–
2.08%	$70.5	$36.7	$40.6	92.3	85.7	-19.3%	-25.1%
1.71%	$67.8	$35.6	$39.3	93.8	87.0	-18.0%	-24.0%
0.72%	$60.9	$32.6	$35.8	98.0	91.3	-14.3%	-20.2%
0.00%	$56.4	$30.6	$33.6	101.3	94.1	-11.5%	-17.7%
-0.32%	$54.6	$29.7	$32.6	102.7	95.5	-10.2%	-16.5%
-0.66%	$52.7	$28.9	$31.6	104.2	96.9	-8.9%	-15.3%
-0.95%	$51.1	$28.1	$30.8	105.7	98.1	-7.6%	-14.2%
-2.62%	$43.2	$24.2	$26.6	114.4	105.4	**0.0%**	-7.9%
-4.60%	$35.7	$20.6	$22.6	123.8	114.4	8.2%	**0.0%**
			Base Year Value:	114.4			

[1] *The amounts shown represent the average annual investment over 20 years by all levels of government combined that would occur if such spending grows annually in constant dollar terms by the percentage shown in each row of the first column.*

[2] *The amounts shown represent the portion of HERS-modeled spending directed toward system rehabilitation, rather than system expansion, which is influenced by the assumption made about future VMT growth rates.*

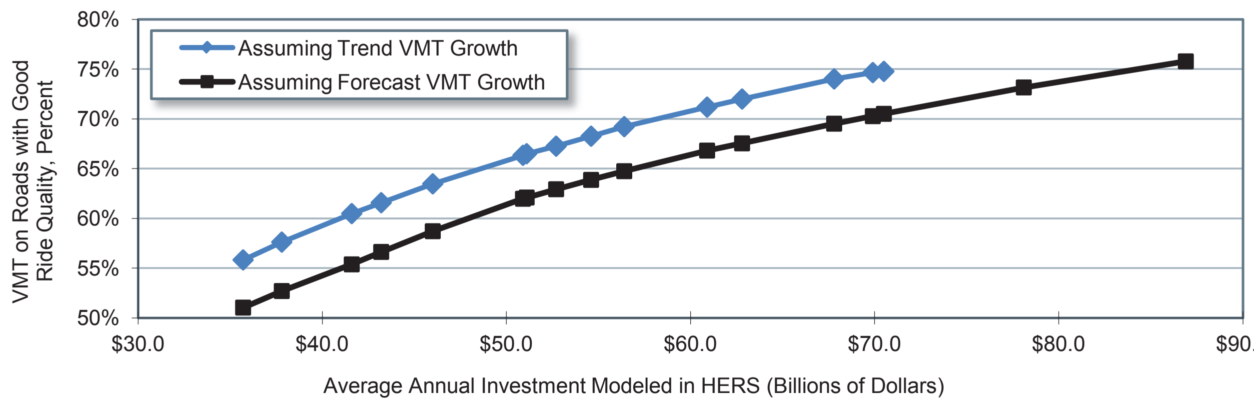
[3] *The HERS model relies on information from the HPMS sample section database, which is limited to those portions of the road network that are generally eligible for Federal funding (i.e., "Federal-aid highways") and excludes roads classified as rural minor collectors, rural local, and urban local.*

Source: Highway Economic Requirements System.

rate (1.85 percent per annum). For those circumstances, HERS projects an 8.2-percent increase in average pavement roughness. The same rate of decline in spending combined with the trend rate of traffic growth (1.36 percent per annum) is projected to maintain the average IRI at the base year level. The rate of spending growth that would maintain average IRI at the 2010 level case is higher when traffic is assumed to grow at the forecast rate, but still negative (-2.62 percent per annum).

Exhibit 7-7 shows the HERS projections for the percentage of travel occurring on pavements with ride quality that would be rated good or acceptable based on the IRI thresholds set in Chapter 3. Under all circumstances represented in the exhibit, the 2030 projection for the percent of travel occurring on pavements with good ride quality exceeds the 50.6 percent that occurred in 2010. With traffic assumed to grow at the forecast rate, the projection for 2030 ranges from 75.8 percent at the highest level of investment modeled, which implements all projects with BCR≥1.0, to 51.0 percent at the lowest level, which would reduce investment at an average annual rate of 4.6 percent. When zero change from the 2010 level of investment is modeled, the projections for 2030 in the forecast growth case are for pavements with good ride quality to carry 64.7 percent of travel. In the trend traffic case, the corresponding projections are 4 to 5 percentage points higher, reflecting the greater share of investment directed toward system rehabilitation.

Exhibit 7-7 Projected 2030 Pavement Ride Quality Indicators on Federal-Aid Highways Compared with 2010, for Different Possible Funding Levels



HERS-Modeled Capital Investment				Projected Impacts on Federal-Aid Highways			
Annual Percent Change in Spending	Average Annual Spending (Billions of 2010 Dollars)			Percent of 2030 VMT on Roads With IRI<95 (Good Ride Quality)[1]		Percent of 2030 VMT on Roads With IRI<170 (Acceptable Ride Quality)[1]	
	Total	System Rehabilitation If Forecast VMT Growth	System Rehabilitation If Trend VMT Growth	If Forecast VMT Growth	If Trend VMT Growth	If Forecast VMT Growth	If Trend VMT Growth
3.95%	$86.9	$43.9	–	75.8%	–	93.4%	–
2.08%	$70.5	$36.7	$40.6	70.5%	74.8%	90.8%	93.1%
1.71%	$67.8	$35.6	$39.3	69.5%	74.0%	90.4%	92.6%
0.72%	$60.9	$32.6	$35.8	66.8%	71.2%	89.1%	91.3%
0.00%	$56.4	$30.6	$33.6	64.7%	69.2%	88.1%	90.3%
-0.32%	$54.6	$29.7	$32.6	63.9%	68.3%	87.6%	89.9%
-0.66%	$52.7	$28.9	$31.6	62.9%	67.3%	87.2%	89.5%
-0.95%	$51.1	$28.1	$30.8	62.1%	66.5%	86.7%	89.1%
-2.62%	$43.2	$24.2	$26.6	56.6%	61.6%	84.0%	86.8%
-4.60%	$35.7	$20.6	$22.6	51.0%	55.8%	81.5%	84.0%
			Base Year Values [2]:	50.6%		82.0%	

[1] *As discussed in Chapter 3, IRI values of 95 and 170 inches per mile, respectively, are the thresholds associated with "good" and "acceptable" pavement ride quality on the NHS.*

[2] *Base Year values shown are 2010 values reported in Chapter 3, rather than those reflected in the 2008 HPMS sample dataset.*

Source: Highway Economic Requirements System.

In almost all the circumstances considered, *Exhibit 7-7* also shows increases relative to the base year level of 82.0 percent in the proportion of travel occurring on pavements with ride quality rated as acceptable. With traffic assumed to grow at the forecast rate, the projection for 2030 ranges from 93.4 percent at the highest level of investment modeled to 81.5 percent at the lowest. When no change from the 2010 level of investment is modeled, 88.1 percent of travel in 2030 in the forecast traffic growth case is projected to occur on pavements with acceptable ride quality. In the trend traffic growth case, the corresponding projections are 2 to 3 percentage points higher. As noted in Chapter 3, the IRI threshold of 170 used to identify acceptable ride quality was originally set to measure performance on the NHS and may not be fully applicable to non-NHS routes, which tend to have lower travel volumes and speeds.

Impact of Future Investment on Highway Operational Performance

Exhibit 7-8 shows the HERS projections for travel time-related indicators of highway performance for the case where traffic grows as forecast in the HPMS. As noted above, HERS assumes the continuation of existing trends in the deployment of certain system management and operations strategies. Among these strategies are several, such as freeway incident management programs, that can be expected to mitigate delay associated with isolated incidents more than the delay associated with recurring congestion ("congestion delay"). In line with this, *Exhibit 7-8* shows the amount of incident delay decreasing relative to congestion delay over the period 2010-2030. Assuming that investment within the scope of HERS remains in real terms at its 2010 level, the model projects incident delay per VMT on Federal-aid highways to decrease 10.3 percent between 2010 and 2030, and congestion delay to increase 12.9 percent.

The results in *Exhibit 7-8* also reveal investment within the scope of HERS to be a potent instrument for reducing congestion delay. *Exhibit 7-8* splits out the portion of that investment that HERS programs for system expansion (such as the widening of existing highways or building new routes in existing corridors), which will tend to reduce congestion delay more than spending on system rehabilitation.

When average annual total investment is assumed to be sustained at the 2010 level of $56.4 billion, total delay per VMT in 2030 is projected to be 1.9 percent higher than in 2010. If instead annual total investment is assumed to average the $86.9 billion that HERS estimates would be needed to fund all

Q&A

How large is the investment backlog estimated by HERS?

The investment backlog represents all improvements that could be economically justified for immediate implementation, based solely on the current conditions and operational performance of the highway system (without regard to potential future increases in VMT or potential future physical deterioration of pavements).

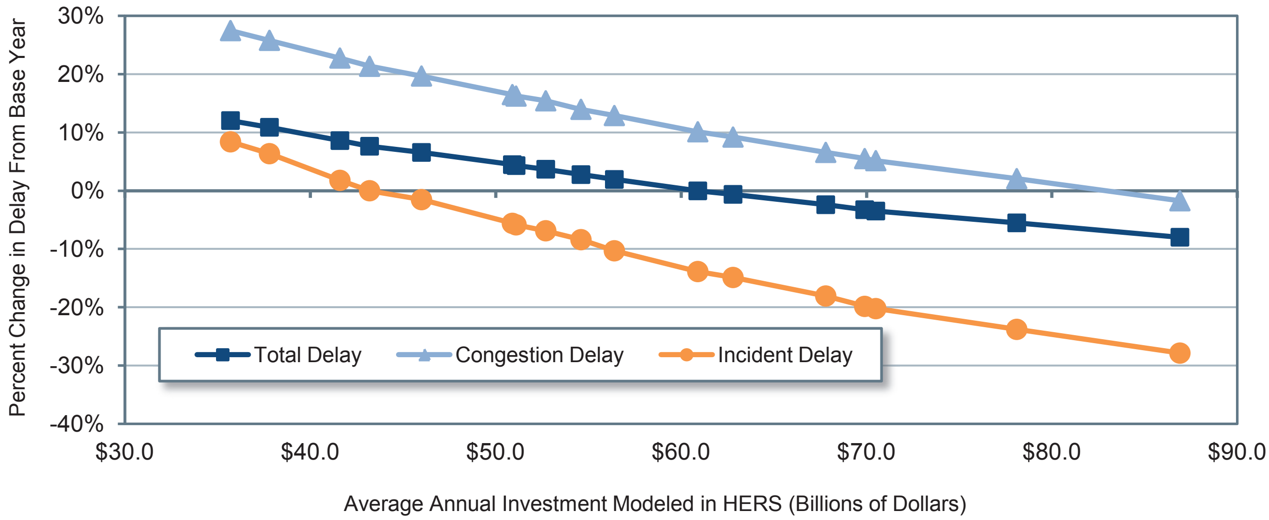
The HERS model does not routinely produce rolling backlog figures over time as an output, but is equipped to do special analyses to identify the base year backlog. To determine which action items to include in the backlog, HERS evaluates the current state of each highway section before projecting the effects of future travel growth on congestion and pavement deterioration. Any potential improvement that would correct an existing pavement or capacity deficiency and that has a BCR greater than or equal to 1.0 is considered part of the current highway investment backlog.

HERS estimates the size of the backlog as $486.6 billion for Federal-aid highways, stated in constant 2010 dollars. The estimated backlog for the Interstate System is $145.9 billion; adding in other principal arterials produces an estimated backlog of $344.8 billion for the expanded NHS. The investment levels associated with a minimum BCR of 1.0 presented in this chapter would fully eliminate this backlog, as well as addressing other deficiencies that arise over the next 20 years, when it is cost beneficial to do so.

It should be noted that these figures reflect only a subset of the total highway investment backlog; they do not include the types of capital improvements modeled in NBIAS (presented later in this chapter) or the types of capital improvements not currently modeled in HERS or NBIAS. Chapter 8 presents an estimate of the combined backlog for all types of improvements.

improvements with BCR≥1.0, the projected change in total delay per VMT is a reduction of 8.0 percent from the 2010 level. For annual congestion delay per vehicle in 2030, the projections indicate that the effect of this difference in investment levels is to save 5.1 hours (47.1 hours assuming $86.9 billion per year versus 52.4 hours at actual 2010 spending). In contrast, at assumed investment levels much lower than what was spent in 2010, the projections are for significant increases in congestion delay per VMT—12.0 percent at the lowest level of investment considered, an annual average of $35.7 billion.

Exhibit 7-8 Projected Changes in 2030 Highway Travel Delay and Speed on Federal-Aid Highways Compared with Base Year, for Different Possible Funding Levels



HERS-Modeled Capital Investment			Projected Impacts on Federal-Aid Highways [1]				
Annual Percent Change in Spending	Average Annual Spending (Billions of 2010 Dollars) Total [2]	System Expansion [3]	Annual Hours of Delay per Vehicle [4]	Percent Change Relative to Baseline: Total Delay per VMT	Congestion Delay per VMT	Incident Delay per VMT	Average Speed in 2030 (mph)
3.95%	$86.9	$43.0	47.3	-8.0%	-1.7%	-27.9%	44.3
2.08%	$70.5	$33.9	49.6	-3.5%	5.2%	-20.2%	43.8
1.71%	$67.8	$32.2	50.2	-2.4%	6.6%	-18.1%	43.7
0.72%	$60.9	$28.3	**51.4**	**0.0%**	10.1%	-13.9%	43.5
0.00%	$56.4	$25.9	52.4	1.9%	12.9%	-10.3%	43.3
-0.32%	$54.6	$24.9	52.8	2.8%	14.0%	-8.4%	43.3
-0.66%	$52.7	$23.8	53.3	3.7%	15.4%	-6.9%	**43.2**
-0.95%	$51.1	$23.0	53.6	4.3%	16.2%	-5.9%	43.1
-2.62%	$43.2	$19.0	55.3	7.6%	21.4%	0.0%	42.8
-4.60%	$35.7	$15.1	57.6	12.0%	27.5%	8.4%	42.3
		Base Year Values:	51.4				43.2

[1] The projected impacts are influenced by the assumption made about future VMT growth rates; this exhibit assumes VMT growth consistent with the HPMS-derived forecast.

[2] The amounts shown represent the average annual investment over 20 years by all levels of government combined that would occur if such spending grows annually in constant dollar terms by the percentage shown in each row of the first column.

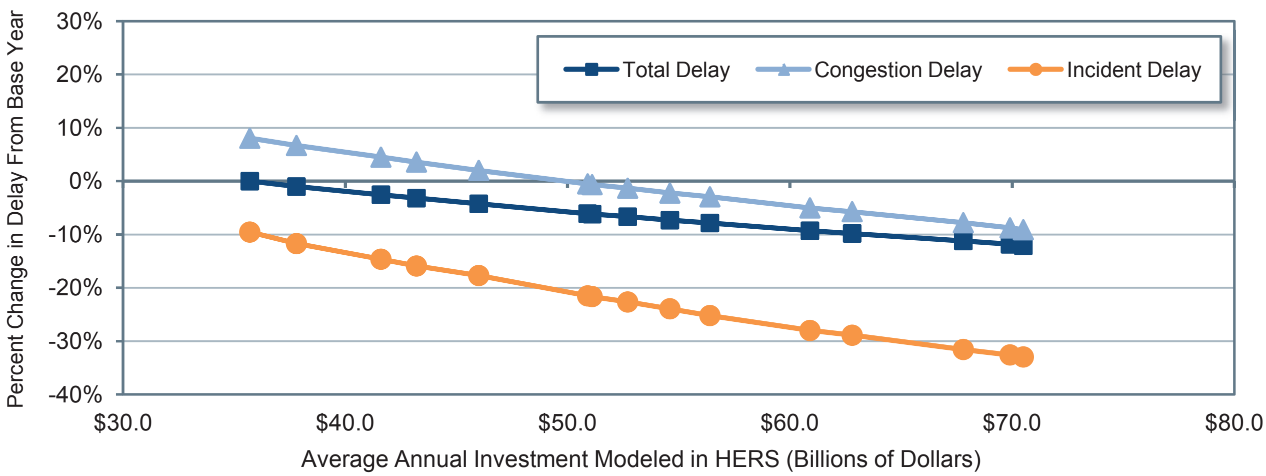
[3] The amounts shown represent the portion of HERS-modeled spending directed toward system expansion, rather than system rehabilitation, which is influenced by the assumption made about future VMT growth rates.

[4] The values shown were computed by multiplying HERS estimates of average delay per VMT by 11,853, the average VMT per registered vehicle in 2010. HERS does not forecast changes in VMT per vehicle over time. The HERS delay figures include delay attributable to stop signs and signals, as well as delay resulting from congestion and incidents.

Source: Highway Economic Requirements System; Highway Statistics 2010, Table VM-1.

Exhibit 7-9 presents results from HERS simulations in which the baseline VMT growth conforms to 15-year historical trend rather than the HPMS forecasts. Because this reduces the rate of VMT growth, the projections of delay for 2030 are lower than in *Exhibit 7-8.* For the case where spending continues at the 2010 level, annual delay per vehicle is projected at 47.4 hours versus the 52.4 hours that was projected in *Exhibit 7-8* when forecast traffic growth was assumed. The impacts on delay of varying the level of investment are somewhat smaller, as well. For example, increasing average annual investment from the 2010 level to $68.4 billion reduces the 2030 projection of annual delay per vehicle by 1.8 hours (from 47.4 to 45.6), whereas the corresponding reduction in *Exhibit 7-8* was 2.2 hours.

Exhibit 7-9 Projected Changes in 2030 Highway Travel Delay and Speed on Federal-Aid Highways Compared with Base Year, for Different Possible Funding Levels, Assuming Trend-Based VMT Growth



HERS-Modeled Capital Investment			Projected Impacts on Federal-Aid Highways [1]				
Annual Percent Change in Spending	Average Annual Spending (Billions of 2010 Dollars) Total [2]	System Expansion [3]	Annual Hours of Delay per Vehicle [4]	Percent Change Relative to Baseline: Total Delay per VMT	Congestion Delay per VMT	Incident Delay per VMT	Average Speed in 2030 (mph)
2.08%	$70.5	$30.0	45.2	-12.1%	-9.1%	-33.0%	44.6
1.71%	$67.8	$28.5	45.6	-11.2%	-7.8%	-31.6%	44.5
0.72%	$60.9	$25.1	**46.6**	**-9.3%**	-5.0%	-28.0%	44.3
0.00%	$56.4	$22.8	47.4	-7.8%	-2.9%	-25.2%	44.2
-0.32%	$54.6	$22.0	47.6	-7.3%	-2.2%	-23.9%	44.2
-0.66%	$52.7	$21.1	48.0	-6.7%	-1.3%	-22.6%	**44.1**
-0.95%	$51.1	$20.3	48.2	-6.2%	-0.7%	-21.6%	44.0
-2.62%	$43.2	$16.6	49.7	-3.2%	3.6%	-15.9%	43.8
-4.60%	$35.7	$13.1	51.4	0.0%	8.0%	-9.5%	43.4
		Base Year Values:	51.4				43.2

[1] The projected impacts are influenced by the assumption made about future VMT growth rates; this exhibit assumes VMT growth consistent with the trend over the 15-year period from 1995 to 2010.

[2] The amounts shown represent the average annual investment over 20 years by all levels of government combined that would occur if such spending grows annually in constant dollar terms by the percentage shown in each row of the first column.

[3] The amounts shown represent the portion of HERS-modeled spending directed toward system expansion, rather than system rehabilitation, which is influenced by the assumption made about future VMT growth rates.

[4] The values shown were computed by multiplying HERS estimates of average delay per VMT by 11,853, the average VMT per registered vehicle in 2010. HERS does not forecast changes in VMT per vehicle over time. The HERS delay figures include delay attributable to stop signs and signals, as well as delay resulting from congestion and incidents.

Sources: Highway Economic Requirements System; Highway Statistics 2010, Table VM-1.

Whichever the traffic growth assumption, forecast or trend, it is important to bear in mind some traffic basics when interpreting these results. In addition to congestion and incident delay, some delay inevitably results from traffic control devices. For this reason, and because traffic congestion occurs only at certain places and times, *Exhibits 7-8* and *7-9* show the variation in the level of investment as having less of an impact on projections for total delay and average speed than on the projections for congestion and incident delay. In addition, while the impacts of additional investment on average speed are proportionally small—when trend traffic growth is assumed, investing enough to implement all cost beneficial projects rather than at the 2010 level increases average speed projected for 2030 from 44.2 mph to 44.6 mph—these impacts apply to a vast amount of travel, so that the associated savings in user cost are not necessarily small relative to the cost of the investment.

Impact of Future Investment on Highway User Costs

In the HERS model, the benefits from highway improvements are the reductions in highway user costs, agency costs, and societal costs of vehicle emissions. In measuring the highway user costs, the model includes the costs of travel time, vehicle operation, and crashes, but excludes from vehicle operating costs taxes imposed on highway users (such as motor fuel taxes and vehicle registration fees). As discussed in the Introduction to Part II, the exclusion of these taxes conforms with the principle in benefit-cost analysis of measuring the costs of transportation inputs as their opportunity cost to society. The exclusion also makes the measure of user costs more of an indicator of highway conditions and performance, of which the amount paid in highway-user taxes provides no indication.

Impact on Overall User Cost

For Federal-aid highways, HERS estimates that user costs—the costs of travel time, vehicle operation, and crashes—averaged $1.030 per mile of travel in the base year (*Exhibit 7-10*). When baseline traffic is assumed to grow as forecast, the average user cost is generally higher in the 2030 projection than in the base year estimate. Average user cost is projected to increase between 2010 and 2030 by 0.8 percent and by 2.1 percent under the assumptions that real annual spending remains at the base year level or, alternatively, decreases annually at the rate geared toward maintaining average pavement roughness (2.62 percent). Decreases in average user cost are projected for the two highest levels of spending considered. At the level HERS indicates would be needed to fund all cost-beneficial projects (averaging $86.9 billion annually), average user cost per mile of travel in 2030 is projected to be $1.018, or 1.1 percent less than in the base year. *Exhibit 7-10* also reveals that assuming baseline traffic growth to follow trend rather than the HPMS forecasts reduces the projections of average user cost at a given level of investment by 1 to 2 percent.

Q&A

How much does HERS modify the baseline projections of VMT?

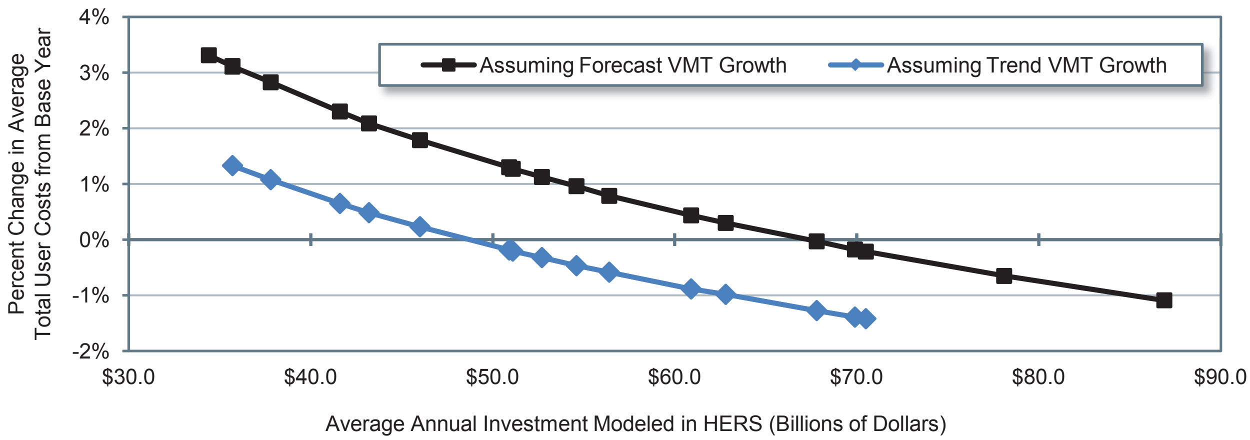
The modification is largest at the lowest investment level presented in *Exhibit 7-10*, which averages $35.7 billion per year and corresponds to negative 4.6 percent annual growth in spending. At this investment level, average user costs are projected to increase between 2010 and 2030 by 3.1 percent when the baseline traffic growth is assumed to be as forecast in HPMS. The projected increase in average user cost operates through the HERS elasticity mechanism to reduce the VMT projection for 2030. The increase from 2.520 trillion VMT in the base year to 3.550 trillion VMT in 2030 translates into an average annual VMT growth rate of 1.73 percent, which falls below the 1.85 percent growth rate forecast in HPMS.

Similarly, when traffic growth is assumed to follow the 15-year trend, average user costs per VMT are projected to increase by 1.3 percent; the increase from 2.520 trillion VMT to 3.253 trillion VMT translates into an average annual VMT growth rate of 1.28 percent, rather than the 1.36 percent annual growth rate assumed if user costs remained constant.

In the present analysis, the percent changes in average user cost are relatively small. For this reason, and because HERS incorporates the indications from available evidence that travel demand is not highly sensitive to price, HERS only slightly modifies the baseline projection of VMT.

The projections in *Exhibit 7-10* for VMT on Federal-aid highways incorporate the effects on travel demand of changes in average user cost. These outputs from the HERS analysis differ from the "trend" and "forecast" projections of VMT on Federal-aid highways that are inputs to the analysis. The input projections, which were shown in *Exhibit 7-2*, are interpreted as representing the baseline levels of traffic in the absence of any change in average user cost from the 2010 level. The 2030 traffic levels presented in *Exhibit 7-10* are thus higher or lower than these baseline levels according to whether average user cost is projected to decrease or increase.

Exhibit 7-10 Projected 2030 Average Total User Costs and VMT on Federal-Aid Highways Compared with Base Year, for Different Possible Funding Levels



HERS-Modeled Capital Investment		Projected Impacts on Federal-Aid Highways*					
Annual Percent Change in Spending	Average Annual Spending (Billions of 2010 Dollars)	Average Total User Costs ($/VMT)		Percent Change in User Costs per VMT, Relative to Base Year		Projected 2030 VMT on Federal-aid Highways (Trillions of VMT)*	
		If Forecast VMT Growth	If Trend VMT Growth	If Forecast VMT Growth	If Trend VMT Growth	If Forecast VMT Growth	If Trend VMT Growth
3.95%	$86.9	$1.018	–	-1.1%	–	3.629	–
2.08%	$70.5	$1.027	$1.015	-0.2%	-1.4%	3.612	3.303
1.71%	$67.8	$1.029	$1.017	0.0%	-1.3%	3.608	3.300
0.72%	$60.9	$1.034	$1.021	0.4%	-0.9%	3.599	3.293
0.00%	$56.4	$1.038	$1.024	0.8%	-0.6%	3.592	3.287
-0.32%	$54.6	$1.040	$1.025	1.0%	-0.5%	3.589	3.285
-0.66%	$52.7	$1.041	$1.026	1.1%	-0.3%	3.586	3.282
-0.95%	$51.1	$1.043	$1.028	1.3%	-0.2%	3.584	3.280
-2.62%	$43.2	$1.051	$1.035	2.1%	0.5%	3.568	3.268
-4.60%	$35.7	$1.062	$1.043	3.1%	1.3%	3.550	3.253
Base Year Values:		$1.030				2.520	

** The HERS model relies on information from the HPMS sample section database, which is limited to those portions of the road network that are generally eligible for Federal funding (i.e., "Federal-aid highways") and excludes roads classified as rural minor collectors, rural local, and urban local.*

Source: Highway Economic Requirements System.

Impact on User Cost Components

Exhibit 7-11 shows the projected changes from 2010 to 2030 in average user cost of travel on Federal-aid highways by cost component. The cost of crashes is the component least sensitive to the assumed level of highway investment, which as an annual average varies between $35.7 billion and $86.9 billion or $70.5 billion depending on whether baseline VMT growth is assumed to follow the HPMS forecast or the 15-year trend. Compared with the lowest level, the highest level of spending reduces the crash cost

per VMT by 0.7 percent (forecast case) or 0.1 percent (trend case). These levels of spending are limited to the types of improvements that HERS evaluates, which are basically system rehabilitation and expansion. Because the HPMS lacks detailed information on the current location and characteristics of safety-related features (e.g., guardrail, rumble strips, roundabouts, yellow change intervals at signals), safety-focused investments are not evaluated. Thus, the findings presented in *Exhibit 7-11* establish nothing about how such investments affect highway safety.

Crash costs also form the smallest of the three components of highway user costs. For 2010 travel on Federal-aid highways, HERS estimates the breakdown by cost component to be crash cost, 13.6 percent; travel time cost, 44.9 percent, and vehicle operating cost, 41.5 percent. Research under way to update the vehicle operating cost equations in HERS (see Appendix D) may somewhat alter the split among these costs, but crash costs will remain a small component. Although highway trips always consume traveler time and resources for vehicle operation, only a small fraction involve crashes. In addition, most crashes are non-catastrophic: particularly on urban highways, many involve only damage to property without anyone being injured.

The projections for the travel time costs are somewhat more sensitive to the assumed level of investment than are the projections for vehicle operating costs. When baseline VMT growth is based on HPMS forecasts, the projected 2010-2030 change in travel cost per VMT ranges from a decrease of 3.5 percent at the highest level of assumed investment to an increase of 2.5 percent at the lowest. This implies that investing at the highest rather than the lowest level would reduce the per VMT cost of travel in 2030 by 5.4 percent (= (035+.025)/(1-.025)). For vehicle operating cost, the corresponding estimate is a reduction of 3.3 percent. When VMT growth is based on trend rather than forecasts, the projections of travel time and vehicle operating cost are lower and less sensitive to variation in the assumed investment level. Investing at the

Exhibit 7-11 Projected Changes in 2030 Average Highway User Costs on Federal-Aid Highways Compared With Base Year, for Different User Cost Components and Different Possible Funding Levels

HERS-Modeled Capital Investment		Projected Impacts on Federal-Aid Highways Percent Change in Average User Costs per VMT in 2030, Relative to Base Year					
		Travel Time Costs		Vehicle Operating Costs [1]		Crash Costs [2]	
Annual Percent Change in Spending	Average Annual Spending (Billions of 2010 Dollars)	If Forecast VMT Growth	If Trend VMT Growth	If Forecast VMT Growth	If Trend VMT Growth	If Forecast VMT Growth	If Trend VMT Growth
3.95%	$86.9	-3.0%	–	0.2%	–	1.1%	–
2.08%	$70.5	-1.8%	-3.9%	1.0%	0.8%	1.3%	0.1%
1.71%	$67.8	-1.6%	-3.7%	1.1%	0.9%	1.3%	0.1%
0.72%	$60.9	-0.9%	-3.2%	1.6%	1.3%	1.4%	0.2%
0.00%	$56.4	-0.4%	-2.8%	1.8%	1.5%	1.5%	0.3%
-0.32%	$54.6	-0.2%	-2.7%	2.0%	1.7%	1.5%	0.3%
-0.66%	$52.7	0.1%	-2.5%	2.1%	1.8%	1.5%	0.4%
-0.95%	$51.1	0.2%	-2.4%	2.3%	1.9%	1.6%	0.4%
-2.62%	$43.2	1.2%	-1.5%	3.2%	2.7%	1.6%	0.4%
-4.60%	$35.7	2.5%	-0.6%	4.1%	3.7%	1.8%	0.6%

[1] *The projected vehicle operating costs are heavily influenced by an assumption drawn from the EIA Annual Energy Outlook 2012 publication that motor fuel prices would grow by 45 percent over the 20 year analysis period. The average retail price of a gallon of gasoline was $2.44 per gallon in 2010, but had already risen to $3.58 by 2011.*

[2] *The HPMS does not contain the type of detail that would be needed to conduct an analysis of targeted safety enhancements. The crash costs estimated by the HERS model represent ancillary impacts associated with pavement and capacity improvements and are heavily influenced by traffic volume and speed.*

Source: Highway Economic Requirements System.

highest level shown for the trend forecast case rather than at the lowest level reduces the projected time cost of travel in 2030 by 3.7 percent and the projected vehicle operating cost by 2.8 percent.

For vehicle operating costs per VMT, all the projections in *Exhibit 7-11* show levels in 2030 to exceed those for 2010. This uniformity contrasts with the mixed pattern in the projections for travel time cost and reflects the assumption of future increases in motor fuel prices. For these prices and for vehicle fuel economy, the assumptions are based on projections from the Energy Information Administration (EIA) *Annual Energy Outlook 2012*. The weighted average price of gasoline and diesel fuel is assumed to increase between 2010 and 2030 by 45 percent more than the consumer price index. This increase outweighs the fuel cost savings that would result from the improvements in vehicle energy efficiency that the EIA projects for this same period; these equate to increases in average MPG of 32.8 percent for light-duty vehicles, 30.0 percent for two-axle trucks, and 19.4 percent for 3+ axle trucks. These projections incorporate the effect of increases in Corporate Average Fuel Economy (CAFE) standards and U.S. Environmental Protection Agency (EPA) standards for emissions of greenhouse gases by automobiles and light trucks through model year 2016, as well as new standards for fuel efficiency and greenhouse gas emissions for medium- and heavy-duty trucks through model year 2018 adopted by U.S. Department of Transportation (DOT) and EPA.

What changes in CAFE standards have recently been adopted, and what impacts are these changes expected to have?

Q&A

On May 7, 2010, NHTSA and EPA jointly adopted Corporate Average Fuel Economy (CAFE) and carbon dioxide (CO_2) emission standards for cars and light trucks produced during model years 2012 through 2016. In combination with NHTSA's previous actions, this rule raised required fuel economy levels for cars from 27.5 miles per gallon (mpg) in model year 2010 to 37.8 mpg for model year 2016, and those for light trucks from 23.5 mpg in 2010 to 28.8 mpg for 2016. On August 28, 2012, the two agencies adopted new rules that further increased CAFE standards for model year 2021 to 46.1 to 46.8 mpg for automobiles and to 32.6 to 33.3 mpg for light trucks; this most recent action also established tentative CAFE standards for model year 2025 of 55.3 to 56.2 mpg for cars and 39.3 to 40.3 mpg for light trucks.

The impacts of these standards on the fuel economy of the overall vehicle fleet will continue to grow for many years beyond 2025, as new vehicles meeting the higher fuel economy requirements gradually replace older, less-fuel-efficient vehicles. In announcing the most recent increases in CAFE standards, NHTSA estimated that the cumulative effects of its actions would be to save more than 500 billion gallons of fuel and reduce carbon dioxide emissions by 6 billion metric tons over the lifetimes of cars and light trucks produced in 2011 through 2025. The agency also estimated that its standards would save the Nation's drivers more than $1.7 trillion in fuel costs over these vehicles' lifetimes.

In 2011, NHTSA and EPA also established new fuel efficiency and CO_2 emission standards for medium- and heavy-duty trucks produced from 2014 through 2018. These standards are expected to reduce fuel consumption by an additional 22 billion gallons, while further reducing CO_2 emissions by nearly 270 million metric tons.

Impacts of NHS Investments Modeled by HERS

As described in Chapter 2, the NHS includes the Interstate System as well as other routes most critical to national defense, mobility, and commerce. As noted earlier, the NHS analyses presented in this chapter are based on an estimate of what the NHS will look like after it is expanded pursuant to MAP-21, rather than the actual system as it existed in 2010.

This section examines the total spending modeled in HERS, identifying the portion of this investment that is directed by the model to the NHS, and the impacts that such investment could have on future NHS conditions and performance. For Federal-aid highways, the preceding analysis in this chapter examined the effect on the HERS projections of replacing the HPMS traffic forecasts with trend traffic growth. In analyzing investments in the NHS portion of Federal-aid highways, this section assumes traffic growth as forecast in the HPMS.

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HERS allocates a portion of future investment in Federal-aid highways to the NHS based on the model's engineering and economic criteria, which give funding priority to high-BCR projects. The levels of future investment in Federal-aid highways considered in this section's analysis are either identical to or counterparts of levels considered in this chapter's preceding sections. Carried over from the preceding analysis are the investment levels tied to a specific minimum BCR among all improvements to the Federal-aid highways that HERS programs over the analysis period. Also included are levels of investment in Federal-aid highways tied to one of the goals considered in the preceding analysis, such as maintaining average pavement roughness at the base year level, except that the goals are now limited to the NHS. In the simulations with these investment levels, HERS allocates to the NHS the amount needed to achieve the goal for the NHS without regard to whether or not the same goal is met for other Federal-aid highways.

How were the seven NHS investment levels presented in *Exhibits 7-12* and *7-13* selected?

Q&A

As MAP-21 directs that the NHS be expanded, the 20-year NHS projections presented in this report were based on all sections coded in HPMS as being on the NHS, plus those other principal arterials that are not currently part of the NHS. While this will not exactly match the scope of the NHS in the future (some sections currently coded as principal arterials may not be ultimately be included in the NHS, and some additional connector mileage may be included), it represents a reasonably close approximation for purposes of the types of analyses presented.

The investment levels associated with minimum BCR cutoffs of 1.00 and 1.50 were derived from the same HERS runs identified in *Exhibit 7-3* as associated with these cutoffs assuming VMT growth consistent with the HPMS-derived forecast. The investment levels shown reflect the portion of spending in those runs that was directed to the NHS.

The remaining five levels were selected using comparable criteria to those identified in *Exhibit 7-3*, but in terms of the NHS in particular, rather than Federal-aid highways in general. The 20-year investment level associated with a minimum BCR cutoff of 1.78 results in an average annual investment level of $40.6 billion, consistent with spending on the NHS in 2010 on types of capital improvements modeled in HERS.

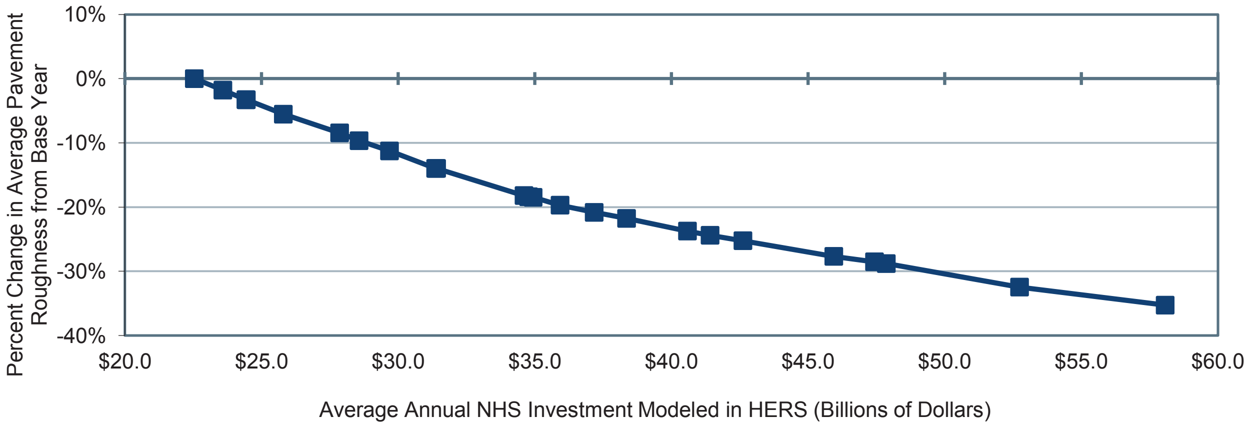
The investment level associated with a minimum BCR cutoff of 2.49 was selected to be included because it results in projected average speed in 2030 matching the base year level. Investing at the level associated with a minimum BCR cutoff of 2.19 is projected to result in average delay being maintained, while applying a minimum BCR cutoff of 2.88 would maintain average IRI. The minimum BCR cutoff of 2.74 was selected as it results in a level of NHS spending that equals the average of the levels associated with maintaining average delay and maintaining average IRI.

Impact of Future Investment on NHS Pavement Ride Quality

Exhibit 7-12 shows the portions of the levels of Federal-aid highway investment considered that HERS allocates to the NHS. To throw light on the projections for NHS pavement quality that are presented, the exhibit also shows the sub-portions of modeled NHS spending that HERS allocates to rehabilitation projects (which influence average pavement quality more than expansion projects). At the assumed level of Federal-aid investment that would cause HERS to allocate to the NHS an annual average of $40.6 billion, matching the level invested in 2010, the model projects average pavement roughness on the NHS will be 23.7 percent lower in 2030 than in 2010. For HERS to project average pavement roughness to remain unchanged between these years would require assuming an annual average NHS spending level of $22.5 billion, an amount that could be achieved if NHS spending declined by 6.01 percent per year beginning in 2010.

At the other end of the investment spectrum in *Exhibit 7-12*, implementing all cost-beneficial improvements would require annual average spending on the NHS estimated at $58.1 billion, which is projected to reduce the average IRI over the analysis period by 35.3 percent. At this level of investment in the system, the model also projects that pavements with an IRI below 95, which was the criterion in Chapter 3 for rating ride quality as "good", will carry 89.6 percent of the VMT on the NHS, up from the 54.7 percent estimated for 2010. Based on these modeling results, additional investment to bring this percentage closer to 100 percent would be economically inefficient, as the costs would exceed the benefits.

Exhibit 7-12 **Projected 2030 Pavement Ride Quality Indicators on the NHS Compared with 2010, for Different Possible Funding Levels**



Minimum BCR Cutoff	HERS-Modeled NHS Capital Investment [1 2]			Projected Impact of HERS-Modeled Capital Investment on the NHS [1]			
	Computed Average Annual Percent Change in Spending [3]	Average Annual Spending (Billions of 2010 Dollars)		Percent of 2030 VMT on Roads With...[5]		Average IRI	
		Total	System Rehabilitation [4]	IRI<95	IRI<170	Projected 2030 Level	Change Relative to Base Year
1.00	3.30%	$58.1	$24.0	89.6%	96.7%	69.0	-35.3%
1.50	1.17%	$45.9	$20.0	83.5%	94.9%	77.1	-27.7%
1.78	**0.00%**	$40.6	$18.2	80.2%	93.9%	81.3	-23.7%
2.19	-1.54%	$34.6	$16.0	75.6%	92.6%	87.2	-18.2%
2.49	-2.51%	$31.4	$14.7	72.2%	91.7%	91.7	-14.0%
2.73	-3.73%	$27.9	$13.2	67.7%	90.5%	97.6	-8.4%
2.88	-6.01%	$22.5	$11.2	61.6%	88.8%	106.6	**0.0%**
			Base Year Values:	**54.7%**	**88.8%**	**106.6**	

[1] *The NHS statistics presented in this chapter are intended to approximate the NHS as it will exist after its expansion directed by MAP-21, not the NHS as it existed in 2010.*

[2] *The seven NHS capital investment levels identified were derived from systemwide HERS runs with the minimum BCR cutoff identified in the first column, based on the portion of these runs directed to the NHS. While the systemwide capital investment for these runs grew at a constant annual rate, this was not the case for the subset of the total spending that was directed to the NHS.*

[3] *The amounts shown represent the average annual growth rate in NHS spending that would generate a cumulative 20-year spending level consistent with the average annual HERS-modeled NHS investment levels identified in the third column. The HERS runs were not actually developed using these growth rates.*

[4] *The portion of HERS-modeled spending directed toward system rehabilitation varies by funding level and is not directly linked to actual spending for this purpose in the baseline year.*

[5] *As discussed in Chapter 3, IRI values of 95 and 170 inches per mile, respectively, are the thresholds associated with "good" and "acceptable" pavement ride quality on the NHS. The base year values shown are 2010 values reported in Chapter 3, rather than those reflected in the 2008 HPMS sample data set.*

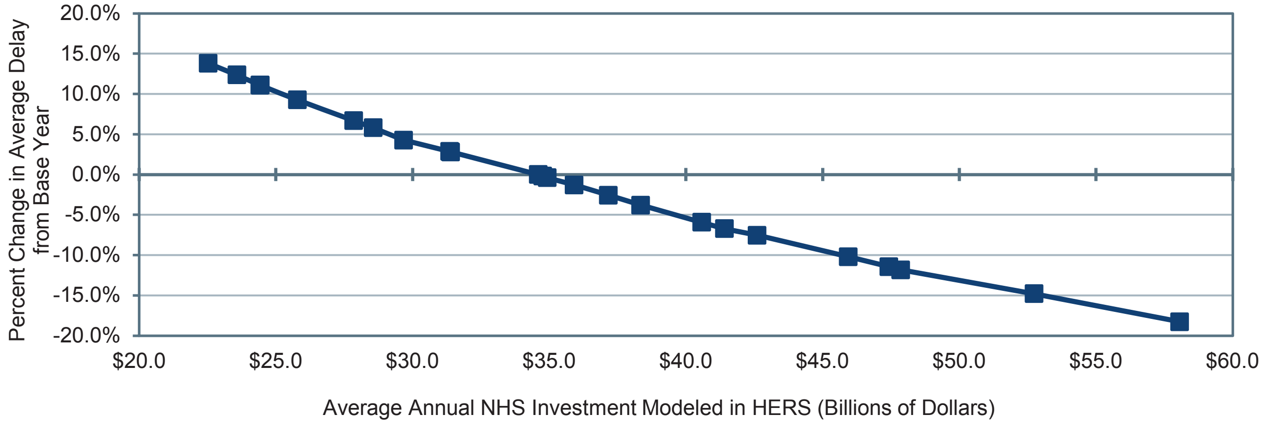
Source: Highway Economic Requirements System.

Impact of Future Investment on NHS Travel Times and User Costs

Exhibit 7-13 presents the projections of NHS averages for time-related indicators of performance, along with the amount that HERS programs for NHS expansion projects (which more than preservation projects affect these indicators). For HERS to project average speed on the NHS to be the unchanged from 2010 to 2030, an annual average of $31.4 billion of NHS spending would be required, a level that could be achieved if annual NHS spending declines by 2.51 percent per year. In contrast, when average annual investment on the

NHS is what would be needed to implement all cost-beneficial improvements, an estimated $58.1 billion, HERS projects average NHS speed to be 4.4 percent higher in 2030 than in 2010 (50.8 mph versus 48.7 mph). At this investment level, HERS also projects for the NHS that average delay will decline by 18.4 percent, and average user cost by 2.4 percent, over the analysis period. For the case where investment in the NHS would remain at the 2010 level, average delay decreases by 5.9 percent, while average user costs are projected to decrease by 0.6 percent.

Exhibit 7-13 Projected Changes in 2030 Delay, Speed, and Highway User Costs on the NHS Compared with 2030 for Different Possible Funding Levels



	HERS-Modeled NHS Capital Investment [1]			Projected Impact of HERS-Modeled Capital Investment on the NHS [1]			
		Average Annual Spending (Billions of 2010 Dollars)		Percent Change Relative to Baseline per VMT		Average Speed	
Minimum BCR Cutoff	Computed Average Annual Percent Change in Spending	Total	System Expansion[2]	Average User Costs	Average Delay	Projected 2030 Level (mph)	Change Relative to Base Year
1.00	3.30%	$58.1	$34.1	-2.4%	-18.3%	50.8	4.4%
1.50	1.17%	$45.9	$25.9	-1.2%	-10.2%	50.0	2.7%
1.78	**0.00%**	$40.6	$22.4	-0.6%	-5.9%	49.6	1.9%
2.19	-1.54%	$34.6	$18.6	0.2%	**0.0%**	49.0	0.6%
2.49	-2.51%	$31.4	$16.7	0.7%	2.8%	48.7	**0.0%**
2.73	-3.73%	$27.9	$14.6	1.5%	6.7%	48.3	-0.9%
2.88	-6.01%	$22.5	$11.4	2.7%	13.8%	47.5	-2.5%
					Base Year Value:	48.7	

[1] The NHS statistics presented in this chapter are intended to approximate the NHS as it will exist after its expansion directed by MAP-21, not the NHS as it existed in 2010.

[2] The portion of HERS-modeled spending directed toward system expansion varies by funding level and is not directly linked to actual spending for this purpose in the baseline year. System expansion expenditures have a more direct impact on delay and speed, while both system expansion and system rehabilitation expenditures impact highway user costs.

Source: Highway Economic Requirements System.

Impacts of Interstate System Investments Modeled by HERS

The Interstate System, unlike the broader NHS of which it is a part, has standard design and signing requirements, which makes it the most recognizable subset of the highway network. This section examines the amount of investment that HERS directs to the Interstate System, and the potential impacts of this investment on future Interstate System conditions and performance. For this analysis, the funding levels presented were selected in the same way as those for the preceding section's analysis of investment in the NHS.

Q&A

How were the seven Interstate System investment levels presented in *Exhibits 7-14* and *7-15* selected?

The investment levels associated with minimum benefit-cost ratio cutoffs of 1.00 and 1.50 were derived from the same HERS runs identified in *Exhibit 7-3* as associated with these cutoffs assuming VMT growth consistent with the HPMS-derived forecast. The investment levels shown reflect the portion of spending in those runs that was directed to the Interstate System.

The remaining five levels were selected using comparable criteria to those identified in *Exhibit 7-3*, but in terms of the Interstate System in particular, rather than Federal-aid highways in general. The 20-year investment level associated with a minimum benefit-cost ratio cutoff of 2.72 results in an average annual investment level of $14.7 billion, consistent with spending on the Interstate System in 2010 on types of capital improvements modeled in HERS.

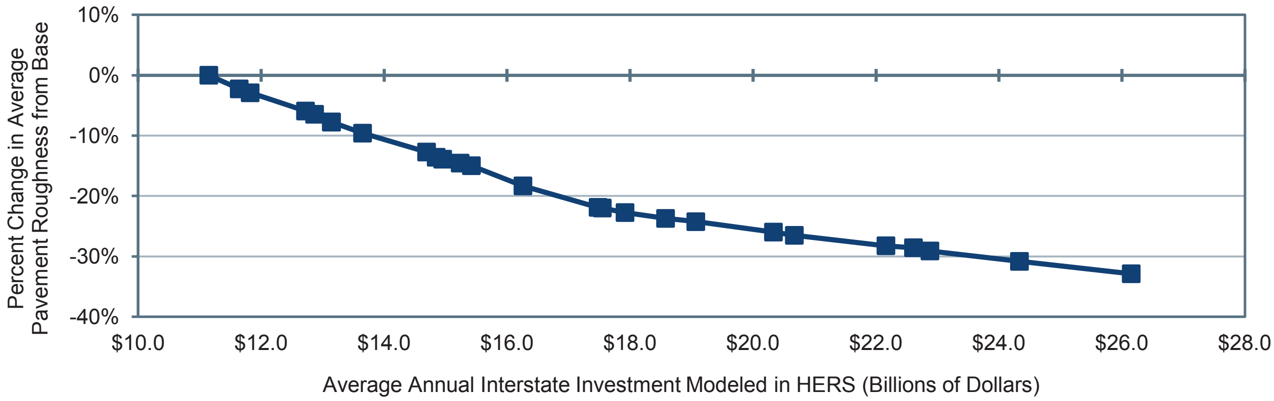
The investment level associated with a minimum benefit-cost ratio cutoff of 2.66 was selected to be included because it results in projected average speed in 2030 matching the base year level. Investing at the level associated with a minimum benefit-cost ratio cutoff of 2.70 is projected to result in average delay being maintained, while applying a minimum benefit-cost ratio cutoff of 2.97 would maintain average IRI. The minimum benefit-cost ratio cutoff of 2.84 was selected as it results in a level of Interstate System spending that equals the average of the levels associated with maintaining average delay and maintaining average IRI.

Impact of Future Investment on Interstate Pavement Ride Quality

Exhibit 7-14 shows the levels of Federal-aid highway investment that HERS allocates to the Interstate System. To throw light on the projections for Interstate System pavement, the exhibit also shows the portion of modeled Interstate System spending that HERS allocates to system rehabilitation projects. At the assumed level of Federal-aid investment that would cause HERS to allocate to the Interstate System an annual average of $14.7 billion, matching the level invested in 2010, the model projects average pavement roughness on the Interstate System to be 12.7 lower in 2030 than in 2010. For HERS to project average pavement roughness to remain unchanged between these years would require assuming a level of Federal-aid highway investment out of which the model would allocate to the Interstate System an annual average of $11.1 billion, which could be achieved with an average annual reduction in spending of 2.71 percent per year starting in 2010.

At the other end of the investment spectrum in *Exhibit 7-14*, implementing all cost-beneficial improvements would require annual average spending on the Interstate System estimated at $26.2 billion; this level of investment is projected to reduce the average IRI over the analysis period by 32.9 percent. At this economically efficient level of investment in the Interstate System, the model also projects that pavements with an IRI below 95, which was the criterion in Chapter 3 for rating ride quality as "good", will carry 94.2 percent of the VMT on the Interstate System, up from the 69.5 percent estimated for 2010.

Exhibit 7-14 Projected 2030 Pavement Ride Quality Indicators on the Interstate System Compared with 2010, for Different Funding Levels



Minimum BCR Cutoff	HERS-Modeled Interstate Capital Investment [1]: Computed Average Annual Percent Change in Spending [2]	Average Annual Spending (Billions of 2010 Dollars): Total	Average Annual Spending (Billions of 2010 Dollars): System Rehabilitation [3]	Projected Impact of HERS-Modeled Capital Investment on the Interstate System: Percent of 2030 VMT on Roads With...[4] IRI<95	Percent of 2030 VMT on Roads With...[4] IRI<170	Average IRI: Projected 2030 Level	Average IRI: Change Relative to Base Year
1.00	5.22%	$26.2	$8.5	94.2%	99.6%	62.3	-32.9%
1.50	3.77%	$22.2	$7.7	90.8%	98.9%	66.6	-28.2%
2.66	0.35%	$15.2	$5.9	81.6%	96.5%	79.3	-14.5%
2.70	0.17%	$15.0	$5.9	81.0%	96.3%	79.9	-13.9%
2.72	**0.00%**	$14.7	$5.8	80.3%	96.2%	81.0	-12.7%
2.84	-1.28%	$12.9	$5.3	76.8%	95.4%	86.8	-6.5%
2.97	-2.71%	$11.1	$4.6	72.1%	94.4%	92.8	**0.0%**
			Base Year Values:	**69.5%**	**90.3%**	**92.8**	

[1] The seven Interstate System capital investment levels identified were derived from systemwide HERS runs with the minimum BCR cutoff identified in the first column, based on the portion of these runs directed to the Interstate System. While the systemwide capital investment for these runs grew at a constant annual rate, this was not the case for the subset of the total spending that was directed to the Interstate System.

[2] The amounts shown represent the average annual growth rate in Interstate System spending that would generate a cumulative 20-year spending level consistent with the average annual HERS-modeled Interstate System investment levels identified in the third column. The HERS runs were not actually developed using these growth rates.

[3] The portion of HERS-modeled spending directed toward system rehabilitation varies by funding level and is not directly linked to actual spending for this purpose in the baseline year.

[4] As discussed in Chapter 3, IRI values of 95 and 170 inches per mile, respectively, are the thresholds associated with "good" and "acceptable" pavement ride quality on the NHS. The base year values shown are based on 2010 values reported in Chapter 3, rather than those reflected in the 2008 HPMS sample data set.

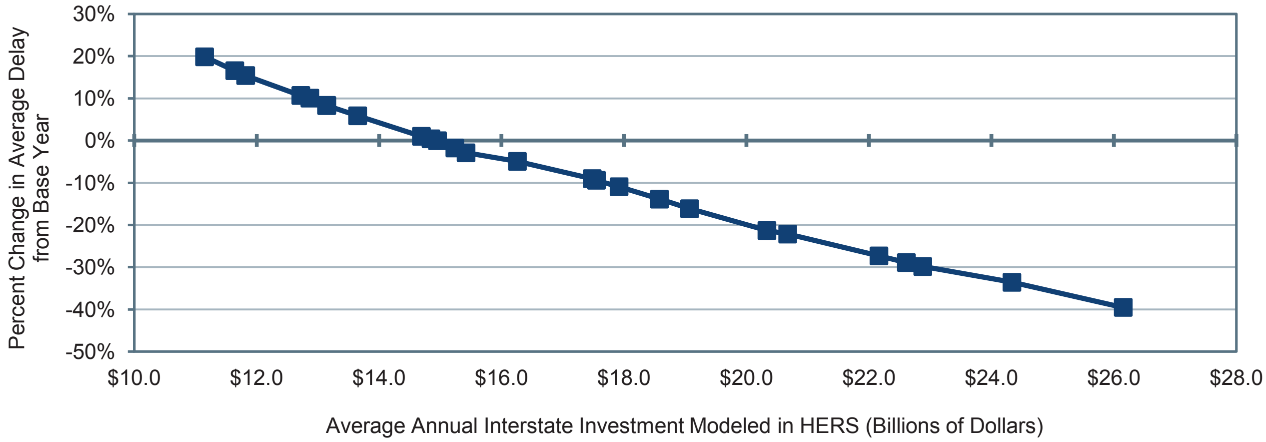
Source: Highway Economic Requirements System.

Impact of Future Investment on Interstate System Travel Times and User Costs

Exhibit 7-15 presents the projections of Interstate System averages for time-related indicators of performance, along with the amount that HERS programs for Interstate System expansion projects. For HERS to project average speed on the Interstate System to be unchanged from 2010 to 2030, an annual average of $15.2 billion of Interstate System spending would be required, which could be achieved if spending increases by 0.35 percent per year beginning in 2010. In contrast, when average annual investment in the Interstate System is what would be needed to implement all cost-beneficial improvements, an

estimated $26.2 billion, HERS projects average Interstate System speed to be 7.5 percent higher in 2030 than in 2010 (64.6 mph versus 60.1 mph). At this investment level, HERS also projects for the Interstate System that average congestion delay will decline by 39.5 percent, and average user cost by 2.9 percent, over the analysis period. For the case where investment in the Interstate System would remain at the 2010 level, average congestion delay and average user cost are each projected to decrease by about one percent.

Exhibit 7-15 Projected Changes in 2030 Speed, Delay, and Highway User Costs on the Interstate System Compared with 2010, for Different Possible Funding Levels



	HERS-Modeled Interstate Capital Investment			Projected Impact of HERS-Modeled Capital Investment on the Interstate System			
	Computed Average Annual Percent Change in Spending	Average Annual Spending (Billions of 2008 Dollars)		Percent Change Relative to Baseline per VMT		Average Speed	
Minimum BCR Cutoff		Total	System Expansion [1]	Average User Costs	Average Delay	Projected 2030 Level (mph)	Change Relative to Baseline
1.00	5.22%	$26.2	$17.6	-2.9%	-39.5%	64.6	7.5%
1.50	3.77%	$22.2	$14.5	-1.9%	-27.3%	63.1	5.0%
2.66	0.35%	$15.2	$9.3	0.6%	-1.7%	60.1	**0.0%**
2.70	0.17%	$15.0	$9.1	0.8%	**0.0%**	60.0	-0.3%
2.72	**0.00%**	$14.7	$8.9	0.9%	1.0%	59.8	-0.5%
2.84	-1.28%	$12.9	$7.6	2.0%	10.1%	58.6	-2.5%
2.97	-2.71%	$11.1	$6.5	3.1%	19.8%	57.6	-4.2%
				Base Year Values:		60.1	

[1] The portion of HERS-modeled spending directed toward system expansion varies by funding level and is not directly linked to actual spending for this purpose in the baseline year. System expansion expenditures have a more direct impact on delay and speed, while both system expansion and system rehabilitation expenditures impact highway user costs.

Source: Highway Economic Requirements System.

National Bridge Investment Analysis System

The scenario estimates relating to bridge repair and replacement shown in this report are derived primarily from NBIAS, which accepts detailed structural data on individual bridge elements. Because such detailed information is not currently available at the national level, NBIAS also has the capability to synthesize element level data from the general condition ratings reported for individual bridges in the National Bridge Inventory (NBI). The analyses presented in this report are based on synthesized element level data. Examples of bridge elements include the bridge deck, a steel girder used for supporting the deck, a concrete pier cap on which girders are placed, a concrete column used for supporting the pier cap, or a bridge railing.

The NBIAS model uses a probabilistic approach to model bridge deterioration for each synthesized bridge element. It relies on a set of transition probabilities to project the likelihood that an element will deteriorate from one condition state to another over a given period of time. Another key input to the model is the overall objective assumed for maintenance, repair, and rehabilitation (MR&R) policies. Previous C&P reports assumed that the bridge owners would follow MR&R policies aimed at minimizing costs, but NBIAS has recently been enhanced to allow alternative assumptions. In this report, the standard assumption is that bridge owners will pursue MR&R policies aimed at achieving a steady state of bridge performance; other assumptions are considered for sensitivity analysis in Chapter 10. Given the assumed policy objective, NBIAS determines an optimal set of MR&R actions to take for each bridge element based on the condition of the element.

To estimate functional improvement needs, NBIAS applies a set of improvement standards and costs to each bridge in the NBI. The model then identifies potential improvements—such as widening existing bridge lanes, raising bridges to increase vertical clearances, and strengthening bridges to increase load-carrying capacity—and evaluates their potential benefits and costs. NBIAS evaluates potential bridge replacements by comparing their benefits and costs with what could be achieved through MR&R work alone. Appendix B discusses the NBIAS model in more detail.

In using the NBIAS model to project conditions and performance of the Nation's bridges over 20 years, this section considers the alternatives of continuing to invest in bridge rehabilitation at the 2010 level (in constant dollars) and at higher or lower levels. The expenditures modeled pertain only to bridge system rehabilitation; expenditures associated with bridge system expansion are modeled separately as part of the capacity expansion analysis in the HERS model. (The NBIAS-modeled investments presented here should be considered as additive to the HERS-modeled investments presented above; each of the capital investment scenarios presented in Chapter 8 combines one of the HERS analyses with one of the NBIAS analyses, and makes adjustments to account for non-modeled spending.)

Performance Measures

The NBIAS model considers bridge deficiencies at the level of individual bridge elements based on engineering criteria and computes an initial value for the cost of a set of corrective actions that would address all such deficiencies. The economic bridge investment backlog represents the combined cost of these corrective actions in those cases where NBIAS estimates it would be cost-beneficial to implement them. Changes in this economic bridge investment backlog over time can be viewed as a proxy for changes in overall bridge conditions.

Previous editions of the C&P report used the economic bridge investment backlog as the sole indicator of bridge system performance. For a more comprehensive view of the impacts of various levels of investment, two new additional metrics have been added for this edition, the average Sufficiency Rating and the average Health Index.

How does the NBIAS definition of bridge deficiencies compare with the information on structurally deficient bridges reported in Chapter 3?

Q&A

NBIAS considers bridge deficiencies and corrective improvements at the level of individual bridge elements. The economic backlog of bridge deficiencies estimated by NBIAS thus consists of the cost of all improvements to bridge elements that would be justified on both engineering and economic grounds. It includes many improvements on bridges with certain components that may warrant repair, rehabilitation, or replacement, but whose overall condition is not sufficiently deteriorated for them to be classified as structurally deficient.

The corrective actions recommended by NBIAS would include those aimed at addressing structural deficiencies, as well as some functional deficiencies. System expansion needs for both highways and bridges are addressed separately as part of the HERS model analysis.

Prior to MAP-21, under the Highway Bridge Program (HBP), the Sufficiency Rating of a bridge served as a factor for determining funding eligibility and as an initial prioritization. This initial prioritization, which was provided annually to the States and known as the "Selection List," was a listing of bridges that were eligible for programming for replacement and rehabilitation (other activities under the HBP with separate and different eligibility criteria such as systematic preventive maintenance were also eligible for programming). The Sufficiency Rating is a numeric value that ranges from 100 to 0, in which 100 represents an entirely sufficient bridge and 0 represents an entirely insufficient or deficient bridge. Its calculation is based on a complex formula involving a number of NBI data fields relating to: structural adequacy and safety (in terms of bridge component condition ratings and a load capacity rating), serviceability and functional obsolescence (in terms of bridge geometric features and appraisal ratings, volume of traffic carried, approach roadway features, deck condition rating, structural evaluation, and whether the bridge is on the Strategic Highway Network [STRAHNET]), and essentiality for public use (in terms of volume of traffic carried, detour length, and whether the bridge is on the STRAHNET). For this report, the investment scenarios presented in Chapter 8 focus on the Sufficiency Rating rather than the economic bridge investment backlog.

The Bridge Health Index is a 0-100 ranking system typically used in the context of decision making for bridge preventative maintenance. Although element condition states are categorical; it is useful to think of the condition of an element at a given time as a point along a continuous timeline from 100 percent in the best state to 100 percent in the worst state. The Health Index merely indicates where the element is along this continuum. To aggregate the element-level result to the bridge level, weights are assigned to the elements according to the economic consequences of element failure. Thus, elements whose failure has relatively little economic effect, such as railings, receive less weight than elements whose failure could close the bridge, such as girders. In general, the lower the Health Index number, the higher the priority for rehabilitation or maintenance of the structure, though other factors also come into play when determining priority of work on bridges.

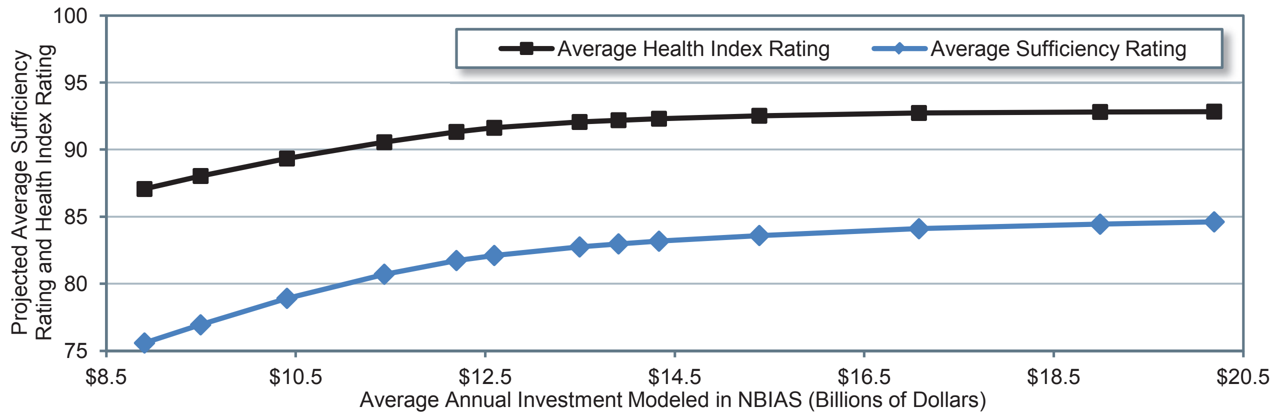
Impacts of Systemwide Investments Modeled by NBIAS

As referenced in Chapter 6, of the $100.2 billion invested in highways in 2010, $17.1 billion was used for bridge system rehabilitation, an increase of more than one-third compared to 2008. This sharp increase is attributable in part to the use of Recovery Act funds to repair and replace bridges.

For investments of the types modeled by NBIAS, *Exhibit 7-16* shows how the total amount invested over the 20-year analysis period influences the bridge performance levels projected for the final year, 2030. If spending were sustained at its 2010 level in constant dollar terms, projected performance for 2030 would improve relative to 2010 for each of the three measures considered. The average Sufficiency Rating would increase from 81.7 in 2010 to 84.1 in 2030, the average Health Index would rise from 92.1 to 92.7; and the economic investment backlog would decrease by 92.6 percent relative to its 2010 level of $106.4 billion. The highest level of spending shown in *Exhibit 7-16* averages $20.2 billion per year, which is the estimate of what would be needed to eliminate the economic backlog by 2030.

Exhibit 7-16 also indicates that bridge investment spending could be reduced from the 2010 level while maintaining bridge performance. If average annual spending declined by 2.30 percent to an average annual investment level of $13.5 billion, this would still be sufficient to maintain the average Health Index at its 2010 level through 2030. An annual decrease in investment of 3.33 percent to an average investment level of $12.2 billion would be adequate to maintain the average Sufficiency Rating at its 2010 level. The economic bridge investment backlog could be maintained at its 2010 level even if annual bridge investment declined by 6.72 percent per year to an average annual level of $8.9 billion.

Exhibit 7-16 Projected 2030 Bridge Condition Indicators for All Bridges, for Different Funding Scenarios



NBIAS-Modeled Capital Investment		Projected Impact of NBIAS-Modeled Capital Investment			
Annual Percent Change in Spending	Average Annual Spending[1] (Billions of 2010 Dollars)	2030 Average Sufficiency Rating	2030 Average Health Index	Economic Investment Backlog[2] 2030 (Billions of 2010 Dollars)	Economic Investment Backlog[2] Change Relative to Baseline
1.57%	$20.2	84.6	92.8	**$0.0**	-100.0%
0.00%	**$17.1**	84.1	92.7	$7.9	-92.6%
-1.70%	$14.3	83.2	92.3	$20.6	-80.6%
-2.30%	$13.5	82.7	**92.1**	$26.4	-75.2%
-3.33%	$12.2	**81.7**	91.3	$39.5	-62.9%
-6.72%	$8.9	75.6	87.1	$106.4	**0.0%**
2010 Baseline Values:		81.7	92.1	$106.4	

[1] The amounts shown represent the average annual investment over 20 years by all levels of government combined that would occur if annual investment grows in constant dollar terms by the percentage shown in each row of the first column.

[2] The amounts shown do not reflect system expansion needs; the bridge components of such needs are addressed as part of the HERS model analysis.

Source: National Bridge Investment Analysis System.

Q&A

Why does the economic backlog estimated by NBIAS differ from bridge backlog figures estimated by some other organizations?

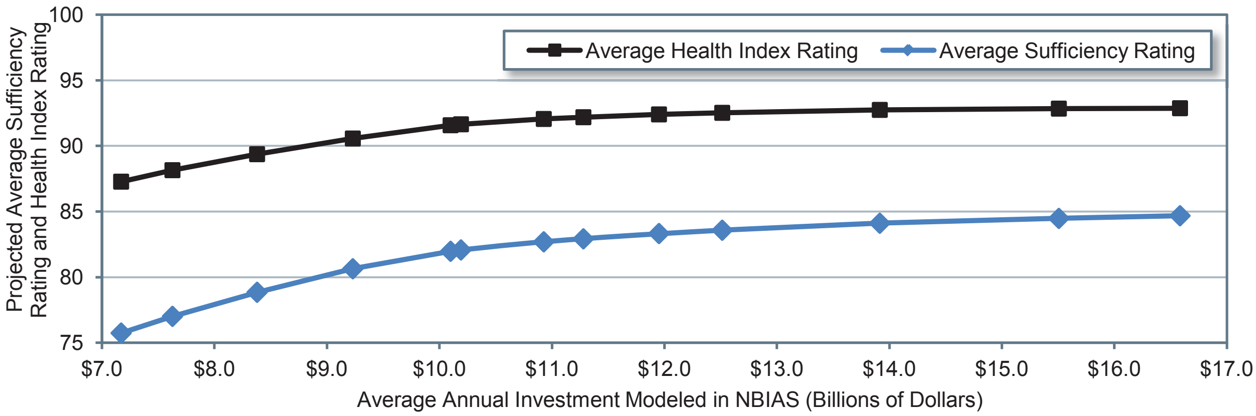
One major reason for such differences is that the backlog estimated by NBIAS is not intended to constitute a complete bridge investment estimate backlog. The NBIAS figures relate only to investment needs associated with the condition of existing structures, and not capacity expansion needs. The backlog estimated by HERS includes estimates of capacity-related needs for highways and bridges combined.

Some estimates of bridge backlog produced by other organizations do attempt to combine estimates of needs relating to bridge capacity with those relating to existing structures.

Impacts of Federal-Aid Highway Investments Modeled by NBIAS

For bridges on Federal-aid highways, *Exhibit 7-17* compares performance projections for 2030 at various levels of investment with measured performance in 2010. If spending on types of improvements modeled in NBIAS were sustained at the 2010 level of $12.5 billion (in constant dollars), the projections show performance improving. The average Sufficiency Rating would increase from 82.0 in 2010 to 83.6 in 2030 and the average Health Index would rise from 92.0 to 92.5; the economic investment backlog would

Exhibit 7-17 Projected 2030 Bridge Condition Indicators for Bridges on Federal-Aid Highways, for Different Possible Funding Levels



NBIAS-Modeled Capital Investment on Federal-Aid Highway Bridges		Projected Impact of NBIAS-Modeled Capital Investment on Federal-Aid Highway Bridges			
				Economic Investment Backlog [2]	
Annual Percent Change in Spending	Average Annual Spending[1] (Billions of 2010 Dollars)	2030 Average Sufficiency Rating	2030 Average Health Index	2030 (Billions of 2010 Dollars)	Change Relative to Baseline
2.61%	$16.6	84.7	92.9	**$0.0**	-100.0%
0.00%	**$12.5**	83.6	92.5	$13.2	-84.8%
-0.44%	$12.0	83.3	92.4	$16.2	-81.3%
-1.31%	$10.9	82.7	**92.0**	$22.8	-73.7%
-2.09%	$10.1	**82.0**	91.6	$30.8	-64.5%
-5.67%	$7.2	75.7	87.3	$86.8	**0.0%**
2010 Baseline Values:		82.0	92.0	$86.8	

[1] The amounts shown represent the average annual investment over 20 years by all levels of government combined that would occur if annual investment grows in constant dollar terms by the percentage shown in each row of the first column. Bridges on roadways functionally classified as rural minor collector, rural local, and urban local are not included in these figures.

[2] The amounts shown do not reflect system expansion needs; the bridge components of such needs are addressed as part of the HERS model analysis.

Source: National Bridge Investment Analysis System.

decrease by 84.8 percent from its 2010 level of $86.8 billion. If spending increases by 2.61 percent per year to an average annual level of $16.6 billion, the economic investment backlog would fall to zero by 2030, while the average Sufficiency Rating would increase to 84.7 and the average Health Index would increase to 92.9.

If spending declined by 1.31 percent per year to an average annual investment level of $10.9 billion, this would still be sufficient to maintain the average Health Index at its 2010 level through 2030. An annual decrease in investment of 2.09 percent to an average investment level of $10.1 billion would be adequate to maintain the average Sufficiency Rating at its 2010 level. The economic bridge investment backlog could be maintained at its 2010 level even if annual bridge investment declined by 5.67 percent per year to an average annual level of $7.2 billion.

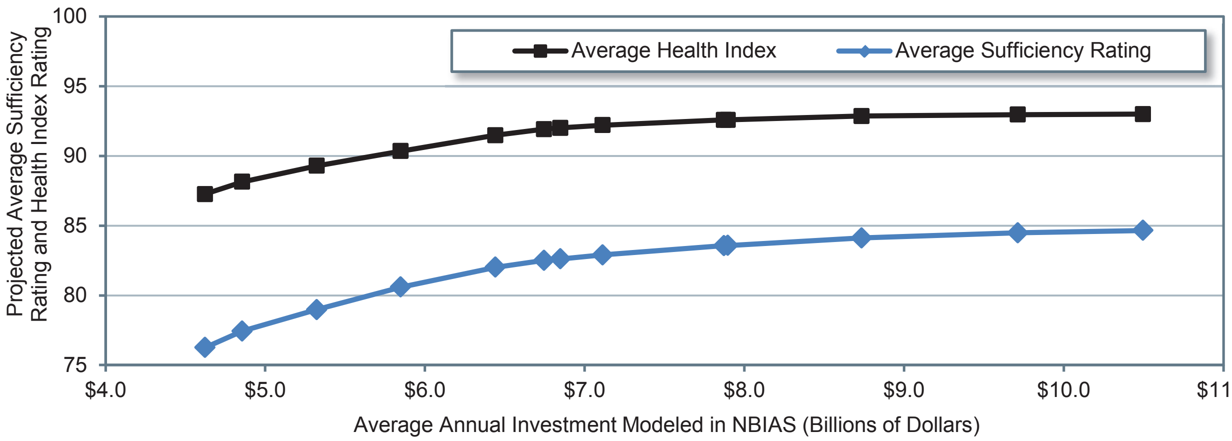
Impacts of NHS Investments Modeled by NBIAS

Exhibit 7-18 shows the impact of varying funding levels on the performance of bridges on the NHS. As noted earlier, the NHS analyses presented in this chapter are based on an estimate of what the NHS will look like after it is expanded pursuant to MAP-21, rather than the actual system as it existed in 2010.

If spending on types of improvements modeled in NBIAS on NHS bridges were sustained at the 2010 level of $8.7 billion in constant dollar terms, projected performance for 2030 would improve relative to 2010. The average Sufficiency Rating would increase from 82.5 in 2010 to 84.1 in 2030, the average Health Index would rise from 92.0 to 92.9, and the economic investment backlog would decrease by 91.7 percent relative to its 2010 level of $59.2 billion. If spending were to increase by 1.72 percent per year to an average annual level of $10.5 billion, this is estimated to be sufficient to reduce the economic investment backlog to zero by 2030, while increasing the average Sufficiency Rating to 84.7 and increasing the average Health Index to 93.0.

If spending declined by 2.38 percent per year to an average annual investment level of $6.8 billion, this would still be sufficient to maintain the average Health Index at its 2010 level through 2030. An annual decrease in investment of 2.53 percent to an average investment level of $6.7 billion would be adequate to maintain the average Sufficiency Rating at its 2010 level. The economic bridge investment backlog could be maintained at its 2010 level even if annual bridge investment declined by 6.55 percent per year to an average annual level of $4.6 billion.

Exhibit 7-18 Projected 2030 Bridge Condition Indicators for Bridges on the NHS, for Different Possible Funding Levels



NBIAS-Modeled Capital Investment on NHS Bridges[1]		Projected Impact of NBIAS-Modeled Capital Investment on NHS Bridges[1]			
				Economic Investment Backlog[3]	
Annual Percent Change in Spending	Average Annual Spending[2] (Billions of 2010 Dollars)	2030 Average Sufficiency Rating	2030 Average Health Index	2030 (Billions of 2010 Dollars)	Change Relative to Baseline
1.72%	$10.5	84.7	93.0	**$0.0**	-100.0%
0.00%	**$8.7**	84.1	92.9	$4.9	-91.7%
-0.97%	$7.9	83.6	92.6	$10.3	-82.6%
-2.38%	$6.8	82.6	**92.0**	$18.9	-68.2%
-2.53%	$6.7	**82.5**	91.9	$19.9	-66.4%
-6.55%	$4.6	76.3	87.3	$59.2	**0.0%**
2010 Baseline Values:		82.5	92.0	$59.2	

[1] The NHS statistics presented in this chapter are intended to approximate the NHS as it will exist after its expansion directed by MAP-21, not the NHS as it existed in 2010.

[2] The amounts shown represent the average annual investment over 20 years by all levels of government combined that would occur if annual investment grows in constant dollar terms by the percentage shown in each row of the first column. Bridges on roadways functionally classified as rural minor collector, rural local, and urban local are not included in these figures.

[3] The amounts shown do not reflect system expansion needs; the bridge components of such needs are addressed as part of the HERS model analysis.

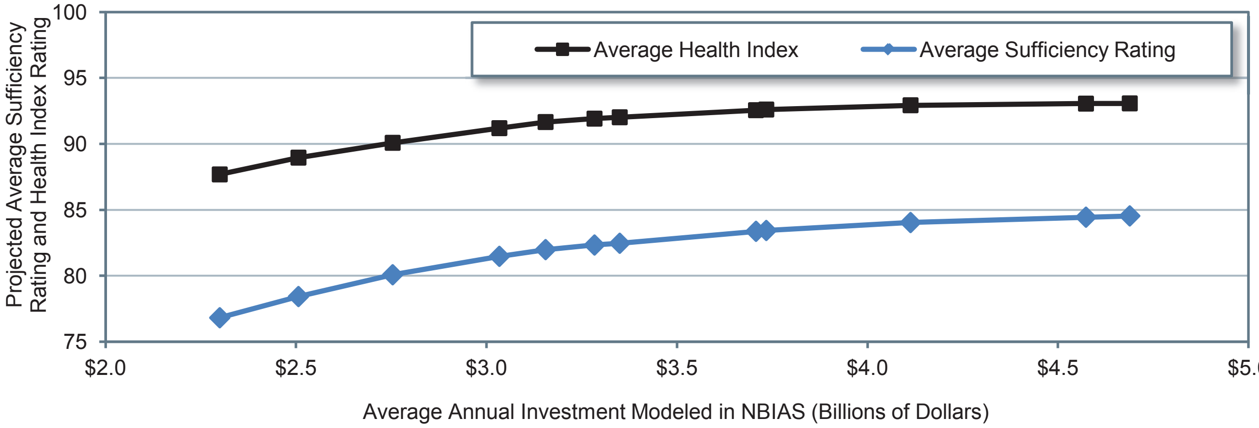
Source: National Bridge Investment Analysis System.

Impacts of Interstate Investments Modeled by NBIAS

Exhibit 7-19 shows the impact of varying funding levels on the performance of those bridges on the Interstate System. If spending on types of improvements modeled in NBIAS on Interstate bridges were sustained at the 2010 level of $4.1 billion in constant dollar terms, projected performance for 2030 would improve relative to 2010. The average Sufficiency Rating would increase from 82.3 in 2010 to 84.0 in 2030, the average Health Index would rise from 91.7 to 92.9, and the economic investment backlog would decrease by 91.4 percent relative to its 2010 level of $30.4 billion. If spending were to increase by 1.23 percent per year to an average annual level of $4.7 billion, this is estimated to be sufficient to reduce the economic investment backlog to zero by 2030, while increasing the average Sufficiency Rating to 84.5 and increasing the average Health Index to 93.1.

If annual spending declined by 2.20 percent per year to an average annual investment level of $3.3 billion, this would still be adequate to maintain the average Sufficiency Rating at its 2010 level through 2030. An annual decrease in investment of 2.60 percent to an average investment level of $3.2 billion would be sufficient to maintain the average Health Index at its 2010 level. The economic bridge investment backlog could be maintained at its 2010 level even if annual bridge investment declined by 5.94 percent per year to an average annual level of $2.3 billion.

Exhibit 7-19 Projected 2030 Bridge Condition Indicators for Bridges on the Interstate System, for Different Funding Levels



NBIAS-Modeled Capital Investment on Interstate Bridges		Projected Impact of NBIAS-Modeled Capital Investment on Interstate Bridges			
Annual Percent Change in Spending	Average Annual Spending[1] (Billions of 2010 Dollars)	2030 Average Sufficiency Rating	2030 Average Health Index	Economic Investment Backlog[2] 2030 (Billions of 2010 Dollars)	Change Relative to Baseline
1.23%	$4.7	84.5	93.1	**$0.0**	-100.0%
0.00%	**$4.1**	84.0	92.9	$2.6	-91.4%
-0.93%	$3.7	83.4	92.6	$5.7	-81.1%
-2.20%	$3.3	**82.3**	91.9	$11.3	-62.7%
-2.60%	$3.2	82.0	**91.7**	$12.8	-57.7%
-5.94%	$2.3	76.8	87.7	$30.4	**0.0%**
2010 Baseline Values:		82.3	91.7	$30.4	

[1] The amounts shown represent the average annual investment over 20 years by all levels of government combined that would occur if annual investment grows in constant dollar terms by the percentage shown in each row of the first column. Bridges on roadways functionally classified as rural minor collector, rural local, and urban local are not included in these figures.

[2] The amounts shown do not reflect system expansion needs; the bridge components of such needs are addressed as part of the HERS model analysis.

Source: National Bridge Investment Analysis System.

Potential Transit Capital Investment Impacts

This section examines how different types and levels of annual capital investments would likely affect transit system condition and performance by the year 2030. It begins with an overview of the types of capital spending projected by the Federal Transit Administration's (FTA's) Transit Economic Requirements Model (TERM), which is the primary analysis tool used to assess transit investment needs and impacts in Part II of this report. The section then examines how variations in the level of annual capital spending are likely to impact future transit conditions and performance—both at the national level and for urbanized areas (UZAs) with populations greater than 1 million.

Types of Capital Spending Projected by TERM

TERM is an analysis tool that uses engineering and economic concepts to forecast total capital investment needs for the U.S. transit industry through a 20-year time horizon. Specifically, TERM is designed to forecast the following types of investment needs:

- **Preservation:** The level of investment in the rehabilitation and replacement of existing transit capital assets required to attain specific investment goals (e.g., to attain a state of good repair [SGR]) subject to potentially limited capital funding.
- **Expansion:** The level of investment in the expansion of transit fleets, facilities, and rail networks required to support projected growth in transit demand (i.e., maintain performance at current levels as demand for service increases).

TERM includes a benefit-cost test that is applied to expansion scenarios to determine which investments are cost effective and which are not; TERM reports investment costs only for investments that pass the test. The SGR benchmark, described in Chapter 8, uses a zero-growth assumption and turns off the cost-benefit test. It estimates the cost of maintaining what is currently in service as an analytical exercise and is not considered to be a realistic scenario.

The data used to support TERM's needs estimates are derived from a variety of sources—including asset inventory data provided by local transit agencies (at FTA's request), fleet investment and transit performance data obtained from the National Transit Database (NTD), and transit travel demand forecast data provided by metropolitan planning organizations (MPOs). Appendix C contains a detailed description of the analysis methodology used by TERM.

Preservation Investments

TERM estimates current and future preservation investment needs by first assessing the age and current condition of the Nation's existing stock of transit assets (the results of this analysis were presented in Chapter 3 of this report). TERM then uses this information to assess both current reinvestment needs (i.e., the reinvestment backlog) as well as the expected level of ongoing investment required to meet the life-cycle needs of the Nation's transit assets over the next 20 years, including all required rehabilitation and replacement activities.

Condition-Based Reinvestment. Rather than relying on age alone in assessing the timing and cost of current and future reinvestment activities, TERM uses a set of empirical asset deterioration curves that estimate asset condition (both current and future) as a function of asset type, age, past rehabilitation activities, and possibly past maintenance and utilization levels (depending on asset type). The timing of specific rehabilitation and replacement activities is determined by an asset's estimated condition at the start

of each year over the 20-year forecast horizon, with asset condition declining as the asset ages, triggering reinvestment events at different levels of deterioration and leading ultimately to outright replacement.

Financial Constraints, the Investment Backlog, and Future Conditions. TERM is designed to estimate investment needs with or without annual capital funding constraints. When run without funding constraints, TERM estimates the total level of investment required to complete all of the rehabilitation and replacement needs identified by the model at the time when those investment needs come due (hence, there is no appreciable investment backlog with unconstrained analyses after any initial deferred investment is addressed). In contrast, when TERM is run in a financially constrained mode, there may not be sufficient funding to cover the reinvestment needs of all assets, in which case some reinvestment activities are deferred until a future period when sufficient funds become available. The lack of sufficient funds to address all reinvestment needs for some or all years of the 20-year model results in varying levels of investment backlog during this time period. Most analyses presented in this chapter were completed using funding constraints. Similarly, TERM's ability to estimate asset conditions—both current and future—allows for assessment of how future asset conditions are likely to improve or decline given varying levels of capital reinvestment. Finally, note that TERM's benefit-cost analysis is utilized to determine the order in which reinvestment activities are completed when funding capacity is limited, with investments with the highest benefit-cost ratios addressed first.

Expansion Investments

In addition to ongoing reinvestment in existing assets, most transit agencies also invest in the expansion of their vehicle fleets, maintenance facilities, fixed guideway, and other assets. Investments in expansion assets can be thought of as serving two distinct purposes. First, the demand for transit services typically increases over time in line with population growth, employment, and other factors. To maintain current levels of performance in the face of expanding demand, transit operators must similarly expand the capacity of their services (e.g., by increasing the number of vehicles in their fleets). Failure to accommodate this demand would result in increased vehicle crowding, increased dwell times at passenger stops, and decreased operating speeds for existing services. Second, transit operators also invest in expansion projects with the aim of improving current service performance. Such improvements include capital expansion projects (e.g., a new light rail segment) to reduce vehicle crowding or increase average operating speeds. TERM is designed to assess investment needs and impacts for both types of expansion investments.

Expansion Investments: Maintain Performance

To assess the level of investment required to maintain existing service quality, TERM estimates the rate of growth in transit vehicle fleets required to maintain current vehicle occupancy levels given the projected growth rate in transit passenger miles. In addition to assessing the level of investment in new fleet vehicles required to support this growth, TERM also forecasts investments in the expansion of other assets needed to support projected fleet growth, including bus maintenance facilities and, in the case of rail systems, additional investment in guideway, track work, stations, maintenance facilities, train control, and traction power systems. Asset expansion investment needs are assessed for all agencies reporting to the NTD on a mode-by-mode basis. However, cost-benefit constraints prevent TERM from investing in asset expansion for those agency-modes with low ridership (per vehicle) as compared with the national average.

Expansion Investments: Improve Performance

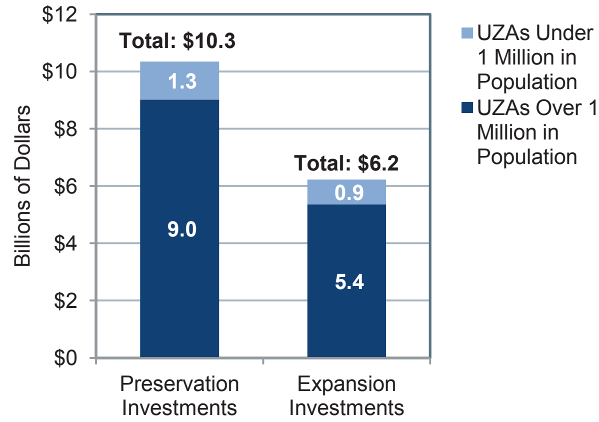
In prior editions of the C&P report, TERM was used to estimate the level of investment required to improve current transit performance by (1) reducing crowding in higher-utilization transit systems and (2) expanding existing investment in rail as a means of improving average operating speeds in urbanized areas with average operating speeds (across all transit modes) well below the national average. For this edition, the impact of increased investment on system performance is assessed by developing TERM scenarios where the rate of investment in transit asset expansion exceeds the projected rate of growth in transit passenger miles. This difference between the rate of asset expansion and actual growth in travel demand represents projected long-term reductions in in-vehicle crowding and potential increases in average operating speed.

Recent Investment in Transit Preservation and Expansion

Exhibit 7-20 shows the broad composition of the 2010 spending by U.S. transit agencies on capital projects that correspond to the investment types modeled in TERM. Of the total spending amounting to $16.5 billion, $10.3 billion or 62.5 percent was devoted to preserving existing assets, and the rest was spent on expansion investments.

As expected, preservation and expansion spending were concentrated in the large urban systems. In combination, urbanized areas with populations greater than 1 million in 2010 accounted for 87.1 percent of preservation spending and 86.1 percent of expansion spending. Smaller urbanized areas and rural areas accounted for the rest.

Exhibit 7-20 2010 Transit Capital Expenditures (Billions of Dollars)



Numbers may not total due to rounding.

Source: National Transit Database.

Impacts of Systemwide Investments Modeled by TERM

This section uses TERM analyses to assess how different levels of investment in the preservation and expansion of the Nation's transit asset base can be expected to impact transit conditions and performance over the next 20 years. A key objective here is to place a broad range of potential future investment levels—and the consequences of those levels of investment—within the context of both the current expenditures on transit preservation and expansion and of some potential investment goals (e.g., attainment of an SGR within 20 years). More specifically, these analyses consider the impact of different levels of transit capital expenditures on the following:

- **Preservation Investments**—Average condition rating of U.S. transit assets and state of good repair backlog
- **Expansion Investments**—Additional ridership (boardings) capacity.

Each of these analyses is completed first at the national level (the remainder of this section) and then repeated (in the following section) for two different segments of urbanized areas, including the following:

- Urbanized areas with populations greater than 1 million
- All other urbanized areas and rural areas with existing transit services.

Impact of Preservation Investments on Transit Backlog and Conditions

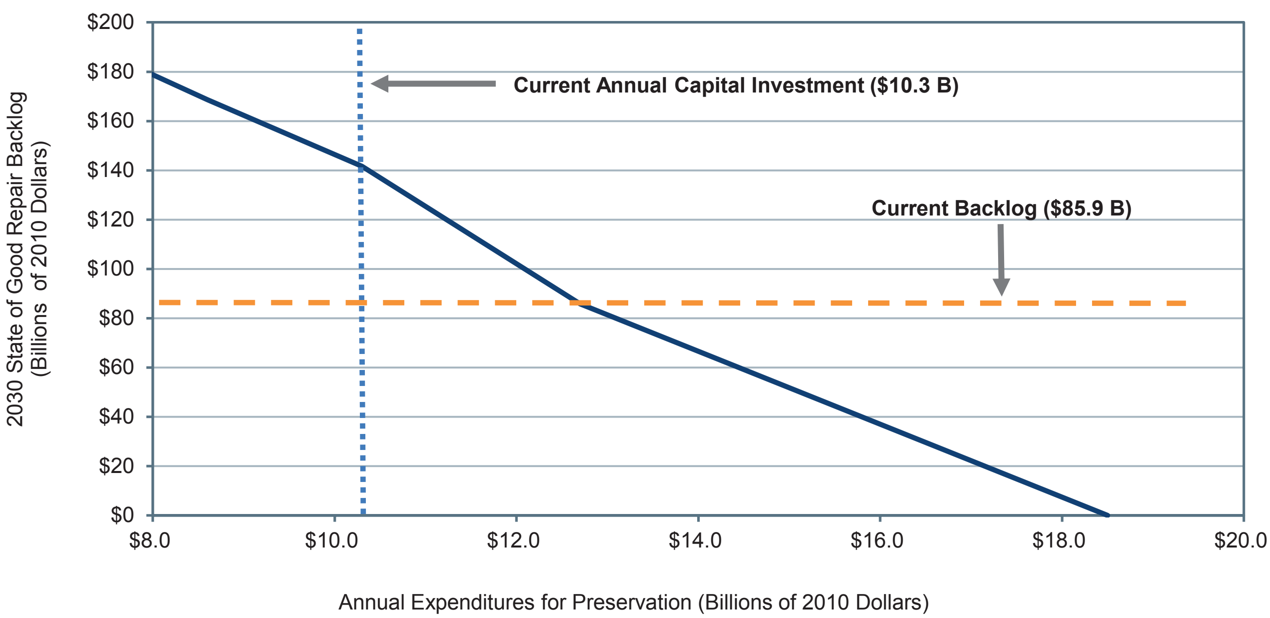
This subsection considers the expected impact of varying levels of aggregate capital reinvestment by all levels of government on the future investment backlog and physical condition (as of 2030) for the Nation's existing stock of transit assets.

Transit Backlog. The 2010 Conditions and Performance Report introduced the concept of reinvestment backlog as an indication of the amount of near-term investment needed to replace assets that are past their expected useful lifetime. It focuses attention on assets that are in the worst condition rather than on the average condition of all assets, which is reported below and has been the primary measure in previous editions. This additional perspective is needed since average condition has become less meaningful in the current environment with high levels of investment in new assets for transit system expansion. Investment backlog is a measure of the need for investment in infrastructure preservation. TERM estimates that investment backlog is $85.9 billion (see Chapter 8).

Exhibit 7-21 focuses on the impact of future spending levels on this investment backlog. Specifically, *Exhibit 7-21* presents the estimated impact of differing levels of annual capital reinvestment on the expected size of the investment backlog in 2030. The investment backlog is defined here as the level of investment required to bring all of the Nation's assets to a state of good repair. This includes replacement of those assets that currently exceed their useful lives (the $85.9 billion) and the performance of all major rehabilitation activities and replacement of assets that will exceed their useful lives during the analysis period. If future reinvestment rates are insufficient to address these ongoing reinvestment needs as they arise, then the size of the backlog will increase over time. Reinvestment at a rate above that required to address new needs as they arise will ultimately result in elimination of the existing backlog.

As shown in *Exhibit 7-21,* TERM analysis suggests that the current rate of capital reinvestment of $10.3 billion is insufficient to keep pace with ongoing rehabilitation and replacement needs and, if maintained over the next 20 years, would result in a reinvestment backlog of roughly $141.7 billion by 2030. In contrast, increasing the annual rate of reinvestment to an average of $18.5 billion will completely eliminate the backlog by 2030. The annual level of reinvestment would need to be increased to roughly $12.7 billion just to maintain the backlog at roughly its current size.

Exhibit 7-21 Impact of Preservation Investment on 2030 Transit State of Good Repair Backlog in All Urbanized and Rural Areas



Average Annual Investment (Billions of 2010 Dollars)	Average Annual Percent Change vs. 2010	Average Condition Rating in 2030	Backlog in 2030 (Billions of 2010 Dollars)	Percent Change From Current Backlog	Funding Level Description
$18.5	5.5%	3.54	$0.0	-100%	SGR (Unconstrained, Replace at 2.50)
$12.7	2.0%	3.48	$85.9	0%	Maintain Current Backlog
$10.3	0.0%	3.39	$141.7	65%	2010 Capital Expenditures (Sustain 2010 Spending)
$8.6	-1.9%	3.34	$168.7	96%	Reduce 2.5 Percent
$6.8	-5.1%	3.28	$199.0	132%	Reduce 5 Percent
$4.4	-9.9%	3.20	$239.5	179%	Reduce 10 Percent
$2.2	-22.2%	3.13	$275.6	221%	Reduce 20 Percent

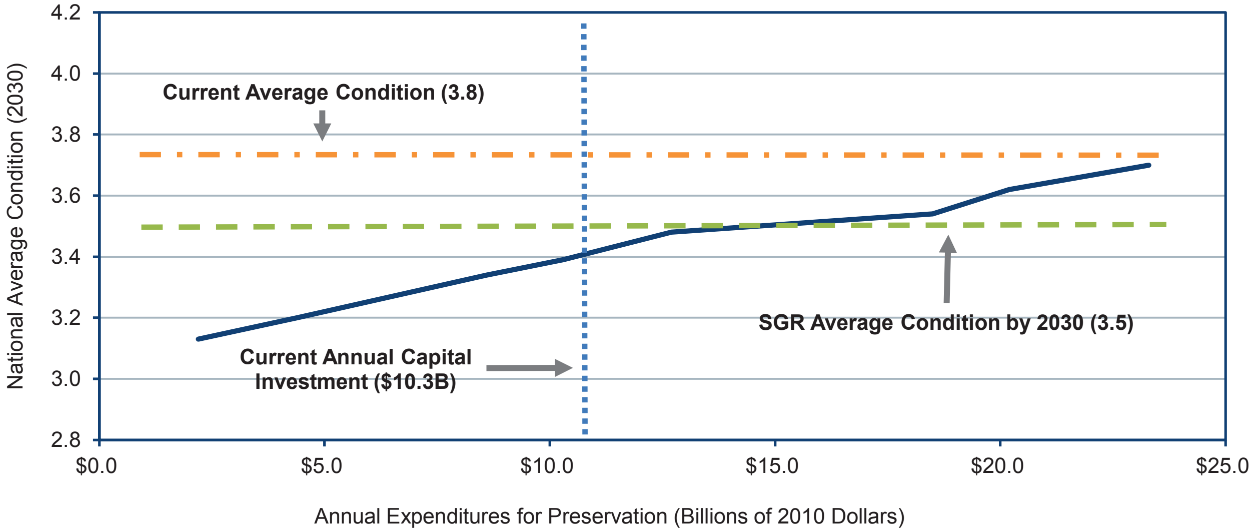
Note that for this report, assets are considered past their useful lives once their estimated condition in TERM falls below condition 2.50.

Source: Transit Economic Requirements Model.

Transit Conditions. *Exhibit 7-22* presents the estimated impact of differing levels of annual rehabilitation and replacement investments on the average physical condition of all existing assets nationwide as of 2030. It shows ongoing improvements to the overall condition of the Nation's existing transit asset base from increasing levels of transit capital reinvestment. It should be emphasized here that average condition provides a measure of asset conditions in the aggregate. Hence, while overall conditions improve with additional expenditures, it should nonetheless be expected that the condition of some individual assets will still deteriorate (given the length of asset lives and the timing of their replacement cycles) while the condition of other assets improves. The value of the aggregate measure lies in providing an overall, single measure of aggregate conditions. Moreover, given the relationship between asset condition and asset reliability, any general improvement in overall asset conditions should also be associated with related improvements to service quality, reliability, and possibly safety.

The table portion of *Exhibit 7-22* presents the same investment and average condition information as in the chart. This table also presents the impact of reinvestment on asset conditions for five key transit asset

Exhibit 7-22 Impact of Preservation Investment on 2030 Transit Conditions in All Urbanized and Rural Areas



Average Annual Investment (Billions of 2010 Dollars) Total Capital Outlay	Average Annual Percent Change vs. 2010	Average Transit Conditions in 2030 — Asset Categories: Guideway	Facilities	Systems	Stations	Vehicles	All Transit Assets	Notes
$23.3	7.5%	3.68	3.80	3.80	3.78	3.37	3.70	Unconstrained, Replace at 3.00
$20.2	6.3%	3.65	3.43	3.70	3.76	3.33	3.62	Unconstrained, Replace at 2.75
$18.5	5.5%	3.58	3.06	3.59	3.74	3.31	3.54	SGR (Unconstrained, Replace at 2.50)
$12.7	2.0%	3.45	2.85	3.55	3.74	3.36	3.48	Maintain Current Backlog
$10.3	0.0%	3.31	2.77	3.40	3.69	3.37	3.39	2010 Capital Expenditures
$8.6	-1.9%	3.26	2.73	3.30	3.67	3.27	3.34	
$6.8	-4.4%	3.22	2.73	3.19	3.66	3.04	3.28	
$4.4	-9.9%	3.21	2.70	3.08	3.64	2.65	3.20	
$2.2	-22.2%	3.17	2.70	2.96	3.63	2.35	3.13	

Note that the conditions of individual transit assets are estimated using TERM's asset decay curves, which estimate asset conditions on a scale of 5 (excellent) through 1 (poor), as described earlier in this chapter and in Appendix C of this report. The average national condition is the weighted average of the condition of all assets nationwide, weighted by the estimated replacement cost of each asset.

Note that this preservation analysis is intended to consider reinvestment needs only for existing transit assets (as of 2010), not for expansion assets to be added to the existing capital stock in future years.

Source: Transit Economic Requirements Model.

categories (i.e., guideway and track, facilities, systems, stations, and vehicles) as well as the average annual percent change in constant dollar funding from 2010 levels to achieve each projected condition level.

Further review of *Exhibit 7-22* reveals several observations. First, note that none of the selected reinvestment rates presented (including the current level of reinvestment, which was $10.3 billion in 2010) is sufficient to maintain aggregate conditions at or near the current national average condition rating of 3.8. Even the highest reinvestment rate presented here of $23.3 billion annually (replacement at condition rating 3.0), which represents a fairly aggressive reinvestment rate, is not quite sufficient to maintain aggregate conditions at current levels. A primary factor driving this result is the ongoing expansion investment in new rail systems over the past several decades, which has tended to maintain or even increase the average condition rating of assets nationwide (despite the ongoing deterioration of older assets), but has also resulted in an average condition rating that is not sustainable in the long term (i.e., without including the influence of further expansion investments or replacing assets at an unreasonably early age). Second, note that reinvestment at roughly $18.5 billion annually is required to attain a condition of SGR by 2030 and that this level of reinvestment is estimated to yield an average condition value of roughly 3.5 by 2030. Given the definition of the SGR benchmark (described in more detail in Chapter 8), which seeks to eliminate the existing investment backlog and then address all subsequent rehabilitation and replacement activities "on time" thereafter, the 3.5 value could be considered representative of the expected long-term average condition of a well-maintained and financially unconstrained national transit system. Hence, an average condition rating of roughly 3.5 represents a more reasonable long-term condition target for existing transit infrastructure than the current aggregate rating of 3.8.

A final observation is that a significant level of reinvestment is required to alter the estimated 2030 average condition measure by a point or more. This result is also driven in part by a large proportion of transit assets with expected useful lives of up to 80 years or more that will not require significant reinvestment over the 20-year period of this analysis (regardless of the level of reinvestment). These assets tend to contribute a high weighting in the average condition measure, making the measure somewhat insensitive to the rate of reinvestment (note that a high proportion of reinvestment activity is focused on the replacement of those assets with relatively shorter useful lives, such as vehicles).

Impact of Expansion Investments on Transit Ridership

While capital spending on preservation primarily benefits the physical condition of existing transit assets, expansion investments are typically undertaken to expand the asset base to accommodate projected growth in ridership and potentially to improve service performance for existing transit system users.

Exhibit 7-23 shows the relationship between aggregated annual capital spending by all levels of government on expansion investments and the additional number of annual passenger boardings that transit systems would be able to support by 2030. More precisely, this chart presents the level of expansion investment required to ensure that transit vehicle occupancy rates are maintained at current levels over the next two decades for a broad range of the potential rates of growth in transit passenger miles traveled (PMT). As the upward sloping curve of the chart indicates, higher levels of investment are required to support greater numbers of additional riders at a constant level of service. If investment levels are insufficient to fully support the projected growth in ridership, then vehicle occupancy rates will tend to increase, leading to increased crowding on high-utilization systems and potentially leading to increased dwell times at stops, reduced average operating speeds, and increased rates of vehicle wear. Conversely, if the rate of transit capacity expansion exceeds the actual rate of ridership growth, then occupancy rates will tend to decline and service performance would likely also improve.

The findings presented in *Exhibit 7-23* suggest the following trends. First, the recent rate of investment in asset expansion ($6.2 billion in 2010) could support roughly 4.6 billion additional boardings by 2030 (approximately a 1.8 percent annual growth in ridership). This amount is greater than that required to support the level of growth projected by the Nation's MPOs (roughly 1.3 percent when adjusted to

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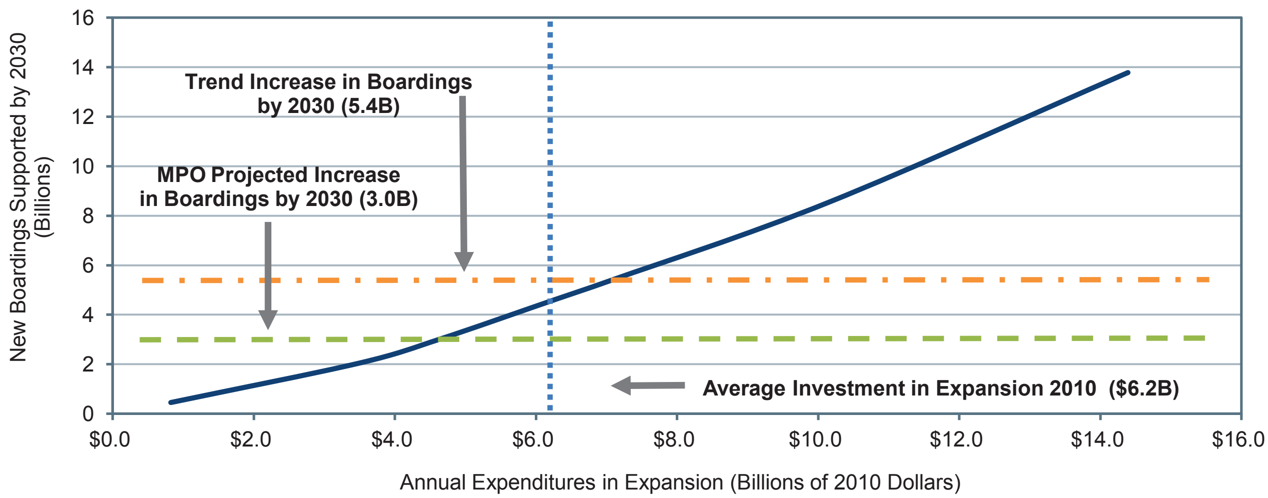
exclude expansion investments that do not pass TERM's benefit-cost test). As discussed in further detail in Chapter 9, MPO projections of transit growth (which are financially constrained) have typically fallen well short of actual growth in recent years. Assuming that the actual rate of ridership growth is close to the trend rate of growth for the last 15 years, then an average of $7.1 billion in annual transit capital expansion investment would be required over the next 20 years to support an additional 5.4 billion annual boardings (again after excluding expansion investments that do not pass TERM's benefit-cost test). Hence, while the existing levels of transit capital expansion investment may be sufficient to maintain current service performance (i.e., vehicle occupancy rates) if ridership growth is relatively low, this level of investment is roughly two-thirds that required to support a level of ridership growth consistent with that experienced over the most recent 15-year period.

Exhibit 7-23 New Ridership Supported in 2030 by Expansion Investments in All Urbanized and Rural Areas



Average Annual Investment (Billions of 2010 Dollars)	Average Annual Percent Change vs. 2010	Total New Boardings by 2030: New Riders Supported (Billions of Annual Boardings)	Total New Boardings by 2030: Average Annual Growth in Boardings*	Funding Level Description
$14.4	7.7%	13.8	4.3%	
$10.2	4.6%	8.5	3.0%	
$7.1	1.3%	5.4	2.1%	Trend Growth in PMT (1995 to 2010)
$6.2	0.0%	4.6	1.8%	2010 Capital Expenditures (Maintain Current Spending)
$4.6	-3.5%	3.0	1.3%	MPO Projected Increase in PMT
$3.5	-6.3%	2.0	0.9%	
$0.8	-36.0%	0.4	0.2%	

** As compared with total urban ridership in 2010; only includes increases covered by investments passing TERM's benefit-cost test.*

Note that TERM assesses expansion needs at the agency-mode level subject to (1) current vehicle occupancy rates at the agency-mode level and (2) expected transit PMT growth at the UZA level (hence, all agency modes within a given UZA are subject to the same transit PMT growth rate). Note, however, that TERM does not generate expansion needs estimates for agency modes that have occupancy rates that are well below the national average for that mode.

Source: Transit Economic Requirements Model.

Impacts of Urbanized Area Investments Modeled by TERM

The remainder of this chapter focuses on how different levels of annual capital investment in the U.S. transit infrastructure affect urbanized areas with dissimilar transit investment needs. Specifically, this section explores the impact of capital expenditures by transit agencies sorted into two distinct UZA groupings: (1) the urbanized areas with populations greater than 1 million and (2) all other urbanized and rural areas with existing transit services.

Urbanized Areas Over 1 Million in Population

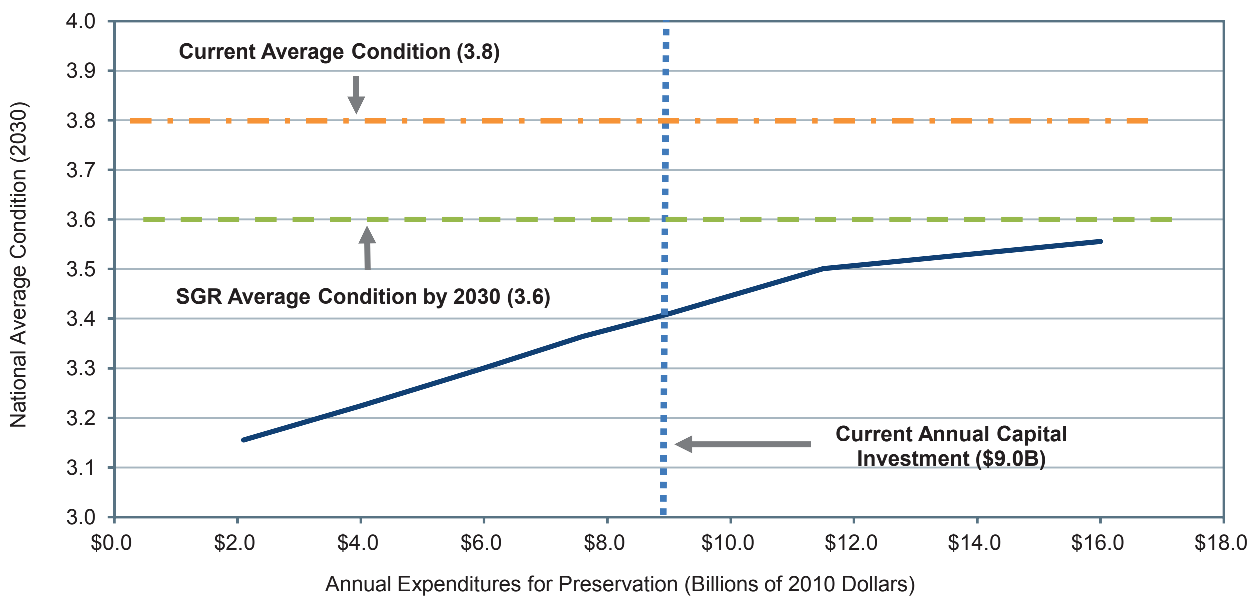
The Nation's largest urbanized areas own and operate the majority of the Nation's existing transit assets. These urbanized areas also typically have the highest levels of investment in older rail assets.

In 2010, transit agencies operating in urbanized areas with populations greater than 1 million expended $14.4 billion on capital projects, consisting of $9.0 billion on preservation investments intended to rehabilitate or replace existing assets, and $5.4 billion on expansion investments designed to increase service capacity. The following is a discussion of the transit asset preservation and expansion needs of these urbanized areas with populations greater than 1 million.

Preservation Investments

Exhibit 7-24 shows the estimated impact of varying levels of preservation investments on the future condition of existing transit assets located in urbanized areas with populations greater than 1 million. As with the earlier chart covering the entire industry, this chart clearly indicates that due to significant recent investments in long-lived expansion assets the current average condition rating for transit assets

Exhibit 7-24 Impact of Level of Preservation Investment on 2030 Transit Conditions in Urbanized Areas Over 1 Million in Population



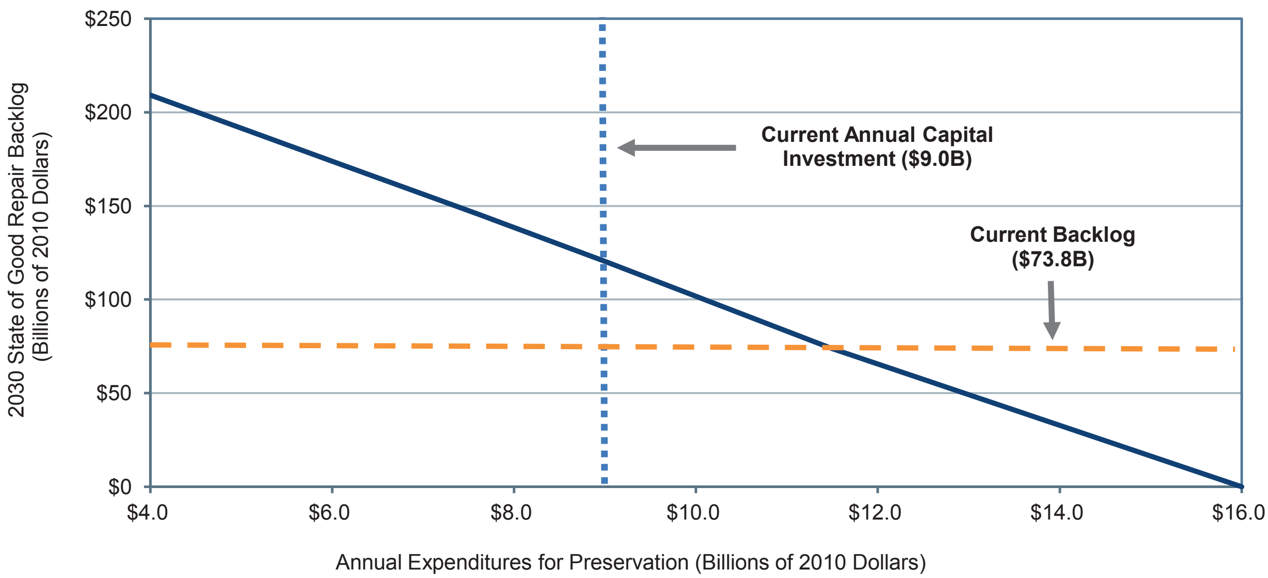
Average Annual Investment (Billions of 2010 Dollars) Total Capital Outlay	Average Annual Percent Change vs. 2010	Average Transit Conditions in 2030 — Asset Categories: Guideway	Facilities	Systems	Stations	Vehicles	All Transit Assets	Notes
$16.0	5.4%	3.54	3.13	3.59	3.74	3.31	3.56	SGR (Unconstrained Condition, Replace at 2.50)
$11.5	2.4%	3.42	2.87	3.55	3.74	3.38	3.50	Maintain Current Backlog
$9.0	0.0%	3.30	2.75	3.41	3.69	3.37	3.41	2010 Capital Expenditures (Maintain Current Spending)
$7.6	-1.7%	3.25	2.70	3.30	3.67	3.28	3.36	Reduce 2.5 Percent
$6.0	-4.3%	3.21	2.69	3.20	3.66	3.03	3.30	Reduce 5 Percent
$4.0	-9.4%	3.19	2.65	3.09	3.64	2.68	3.22	Reduce 10 Percent
$2.1	-20.2%	3.15	2.65	2.96	3.63	2.41	3.15	Reduce 20 Percent

Source: Transit Economic Requirements Model.

located in the largest urbanized areas is not sustainable in the long term without replacing assets on a fairly aggressive schedule (i.e., replacement at or before condition rating 3.0). At the same time, the 2010 level of reinvestment ($9.0 billion) is less than that required to attain a state of good repair ($16.0 billion), with the latter supporting a more sustainable long-term average condition rating of roughly 3.6.

As shown in *Exhibit 7-25,* the 2010 level of capital reinvestment of $9.0 billion for the largest urbanized areas is insufficient to keep pace with ongoing rehabilitation and replacement needs and, if maintained over the next 20 years, would result in a larger SGR backlog of roughly $120.4 billion by 2030 compared with the current $73.8 billion backlog. In contrast, increasing the rate of reinvestment to an annual average of roughly $16.0 billion will completely eliminate the entire backlog by 2030. The annual level of reinvestment would need to be increased to roughly $11.5 billion to maintain the backlog at roughly its current size.

Exhibit 7-25 Impact of Preservation Investment on 2030 Transit State of Good Repair Backlog in Urbanized Areas Over 1 Million in Population



Average Annual Investment (Billions of 2010 Dollars)	Average Annual Percent Change vs. 2010	Replacement Condition	Average Condition Rating in 2030	Backlog in 2030 (Billions of 2010 Dollars)	Funding Level Description
$16.0	5.4%	2.50	3.56	$0.0	SGR (Unconstrained, Replace at 2.50)
$11.5	2.4%	2.50	3.50	$73.8	Current Backlog
$9.0	0.0%	2.50	3.41	$120.4	2010 Capital Expenditures
$7.6	-1.7%	2.50	3.36	$145.7	
$6.0	-4.3%	2.50	3.30	$173.9	
$4.0	-9.4%	2.50	3.22	$209.2	

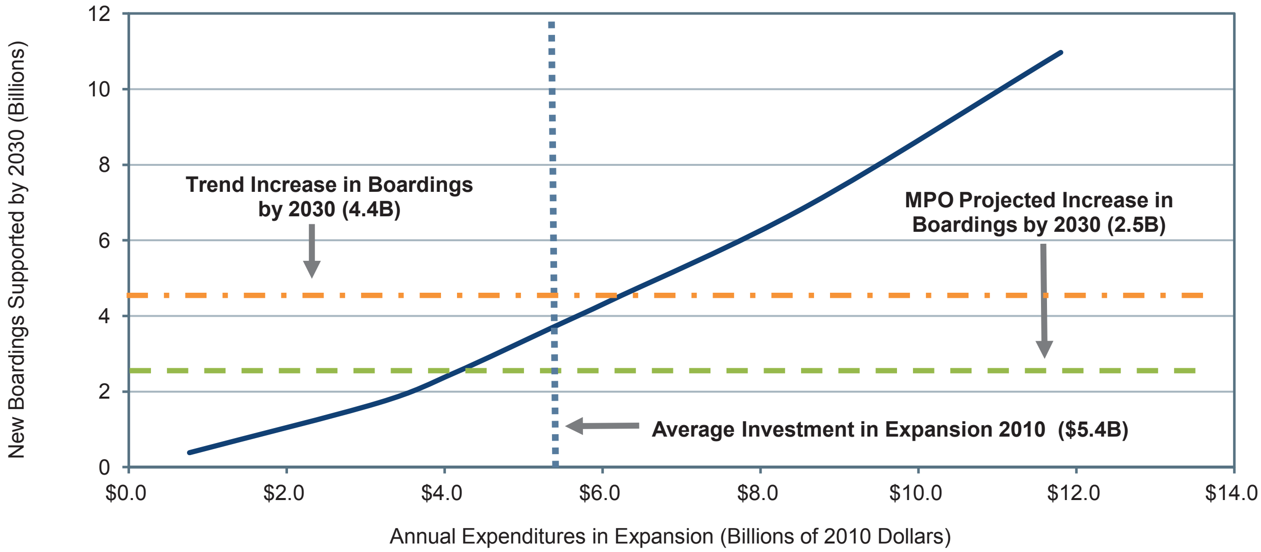
Source: Transit Economic Requirements Model.

Expansion Investments

Although urbanized areas with populations greater than 1 million tend to be cities with slower rates of increase in population and transit ridership (e.g., Boston, Philadelphia, and Chicago), this group also includes urbanized areas expected to experience relatively high rates of growth in transit boardings and PMT over the next two decades, including Los Angeles, Atlanta, and Seattle. Given the high numbers of existing riders and transit capacity in these higher-growth large urbanized areas, they will require significant increases in expansion investments to maintain current service performance during this time period.

Exhibit 7-26 presents estimates of the level of expansion investment required to support varying levels of growth in transit demand while maintaining current performance levels (as measured by vehicle capacity utilization) for these large urbanized areas. Note that the 2010 level of investment for these urbanized areas ($5.4 billion) was more than that required to support the rate of increase in transit demand as projected by the Nation's MPOs (low growth) but well short of that required to support a rate of growth comparable to the trend rate of increase as experienced in recent years.

Exhibit 7-26 New Ridership Supported in 2030 by Expansion Investments in Urbanized Areas Over 1 Million in Population



Average Annual Investment (Billions of 2010 Dollars)	Average Annual Percent Change vs. 2010	Total New Boardings by 2030: New Riders Supported (Billions of Annual Boardings)	Total New Boardings by 2030: Average Annual Growth in Boardings*	Funding Level Description
$11.8	7.3%	11.0	4.0%	
$8.6	4.5%	6.9	2.8%	
$6.1	1.3%	4.4	2.0%	Trend Growth in PMT (1995 to 2010)
$5.4	0.0%	3.7	1.7%	Maintain Spending (2010)
$4.1	-2.8%	2.5	1.2%	MPO Projected Growth
$3.2	-5.6%	1.7	0.8%	
$0.8	-31.8%	0.4	0.2%	

** As compared with total urban ridership in 2010; only includes increases covered by investments passing TERM's benefit-cost test.*

Source: Transit Economic Requirements Model.

Other Urbanized and Rural Areas

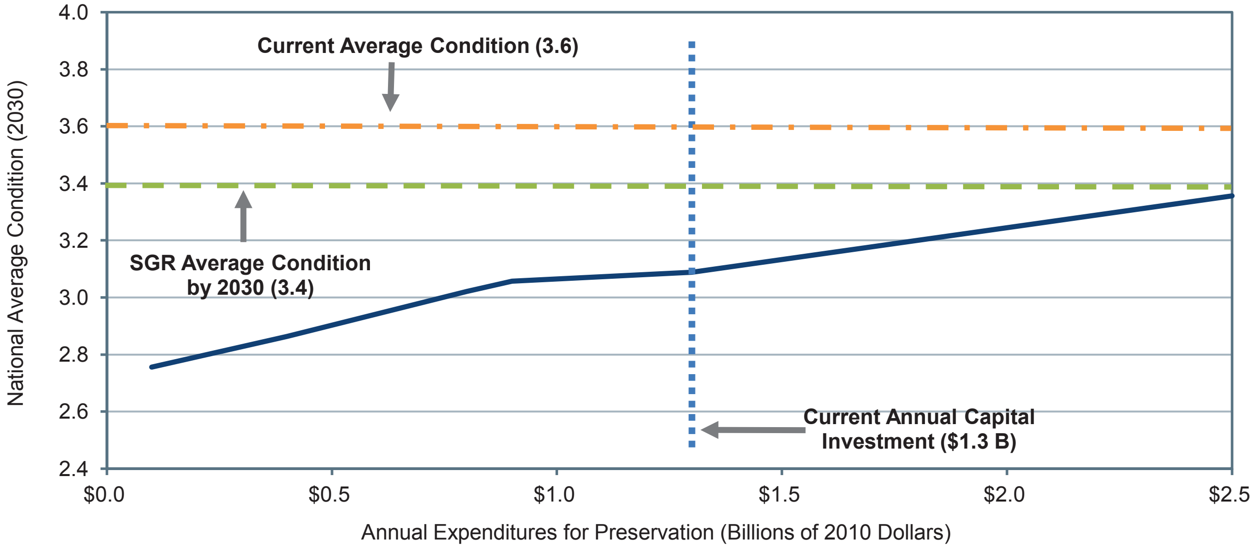
The following analysis considers the combined preservation and expansion needs of urbanized areas under 1 million in population and those of all rural areas with existing transit service. This diverse group therefore includes a large number of mid- and small-sized urbanized and rural transit operators offering only bus and/or paratransit services.

In 2010, transit agencies operating outside of the largest urbanized areas expended $2.2 billion on capital projects, consisting of $1.3 billion on preservation investments intended to rehabilitate or replace existing assets, and $0.9 billion on expansion investments designed to increase service capacity. The following is a discussion of the transit asset preservation and expansion needs of transit agencies in these areas.

Preservation Investments

Exhibit 7-27 shows the estimated impact of varying levels of preservation investments on the future condition of existing transit assets located in urbanized areas with populations less than 1 million and in rural areas. As with the earlier analyses for the largest urbanized areas, this chart also indicates that the current average condition rating for transit assets in these smaller urbanized and rural areas is not sustainable in the long term without replacing assets on a fairly aggressive schedule (i.e., replacement at or before condition rating 3.0). At the same time, the 2010 level of reinvestment ($1.3 billion) is significantly less than that required to attain an SGR ($2.5 billion), with the latter supporting a more sustainable long-term average condition rating of roughly 3.4.

Exhibit 7-27 Impact of Preservation Investment on 2030 Transit Conditions in Urbanized Areas Under 1 Million in Population

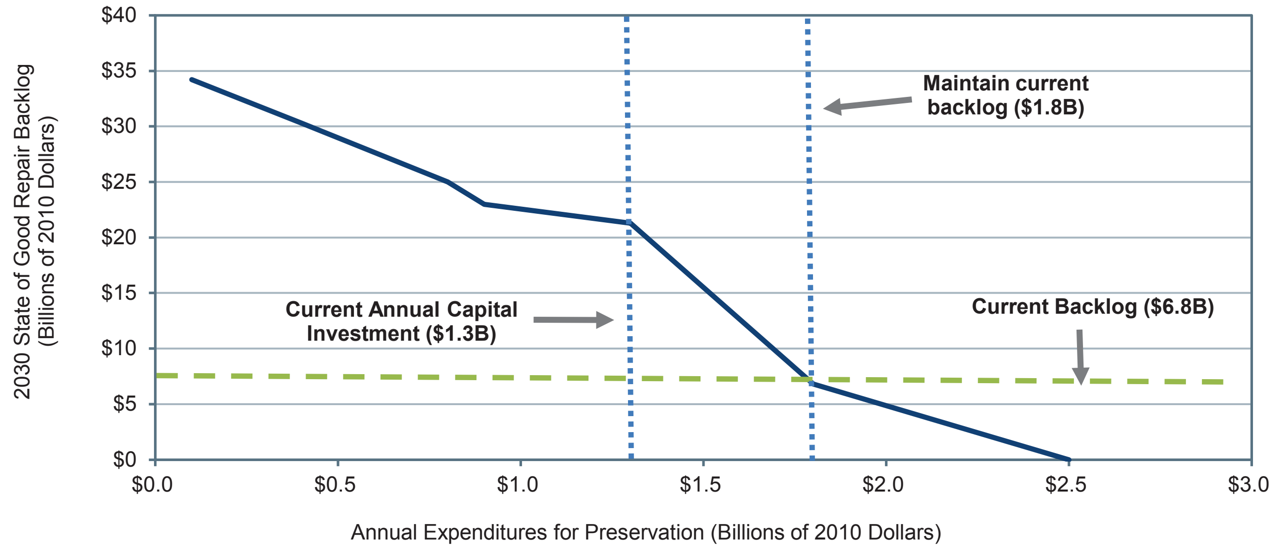


Average Annual Investment (Billions of 2010 Dollars) Total Capital Outlay	Average Annual Percent Change vs. 2010	Average Transit Conditions in 2030 Asset Categories: Guideway	Facilities	Systems	Stations	Vehicles	All Transit Assets	Notes
$2.5	7.5%	4.45	2.93	3.73	3.87	3.30	3.36	SGR (Unconstrained, Replace at 2.5)
$1.3	0.0%	3.57	2.79	3.11	3.75	3.32	3.09	2010 Capital Expenditures (Maintain Current Spending)
$0.90	-2.1%	3.57	2.78	3.05	3.51	3.23	3.06	Reduce 2.5 Percent
$0.8	-3.3%	3.57	2.78	3.03	3.41	3.09	3.02	Reduce 5 Percent
$0.4	-12.2%	3.57	2.78	2.99	3.38	2.37	2.86	Reduce 10 Percent
$0.1	-52.1%	3.57	2.78	2.98	3.35	1.88	2.76	Reduce 20 Percent

Source: Transit Economic Requirements Model.

As shown in *Exhibit 7-28,* the 2010 level of capital reinvestment of $1.3 billion for rural areas and smaller urbanized areas is insufficient to keep pace with ongoing rehabilitation and replacement needs. If maintained over the next 20 years, this rate of investment would result in a larger SGR backlog of roughly $21.3 billion by 2030, as compared with the current backlog of $6.8 billion for this group. In contrast, increasing the rate of reinvestment to an annual average of roughly $2.5 billion will completely eliminate the entire backlog by 2030. The annual level of reinvestment would need to be increased to roughly $1.8 billion annually to maintain the backlog at roughly its current size.

Exhibit 7-28 **Impact of Preservation Investment on 2030 Transit State of Good Repair Backlog in Urbanized Areas Under 1 Million in Population**



Average Annual Investment (Billions of 2010 Dollars)	Average Annual Percent Change vs. 2010	Replacement Condition	Average Condition Rating in 2030	Backlog in 2030 (Billions of 2010 Dollars)	Funding Level Description
$2.5	7.5%	2.50	3.36	$0.0	SGR (Unconstrained, Replace at 2.50)
$1.8	4.7%	2.50	3.17	$6.8	Current Backlog
$1.3	0.0%	2.50	3.09	$21.3	2010 Capital Expenditures
$0.9	-2.1%	2.50	3.06	$23.0	
$0.8	-3.3%	2.50	3.02	$25.0	
$0.4	-12.2%	2.00	2.86	$30.3	
$0.1	-52.2%	2.50	2.76	$34.2	

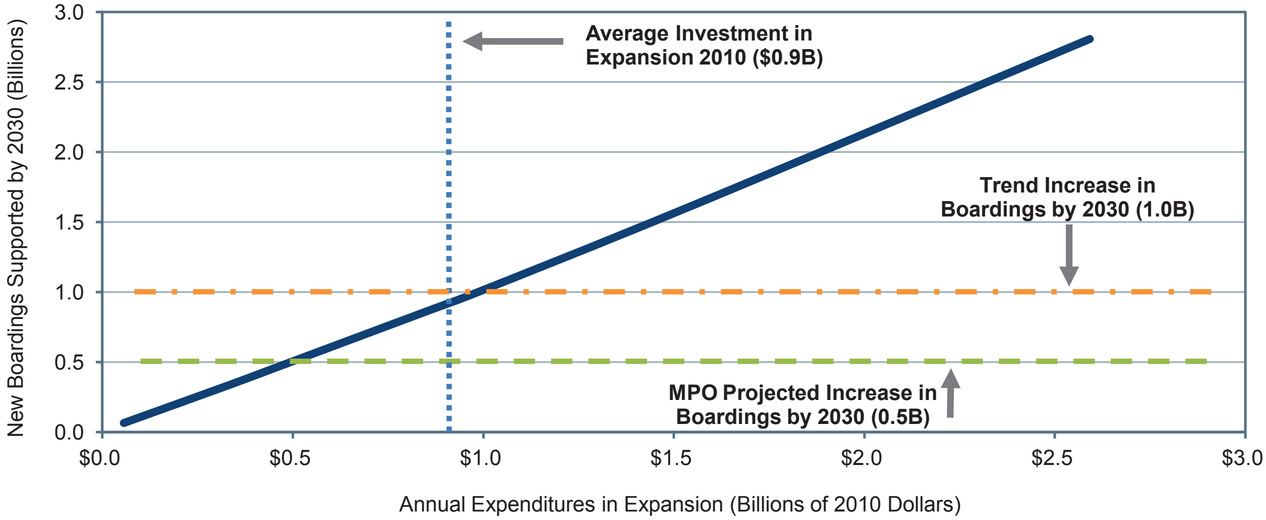
Source: Transit Economic Requirements Model.

Expansion Investments

While the urbanized and rural areas in this group represent a smaller number of riders and a smaller existing transit asset base, these areas are also expected to have a higher projected rate of increase in transit ridership.

Exhibit 7-29 presents estimates of the level of expansion investment required to support varying levels of growth in transit demand while maintaining current performance levels (as measured by transit passenger miles per peak vehicle) for the smaller urbanized and all rural areas. Note that the 2010 level of investment for these areas ($0.9 billion) was the same as that required to support the rate of increase in transit demand as projected by the Nation's MPOs and slightly less than the trend rate of increase as experienced over the last several years. Such investments should yield improvements in transit performance in these urbanized areas and also help promote transit-led urban development in urbanized areas subject to above average rates of population and transit growth.

Exhibit 7-29 New Ridership Supported in 2030 by Expansion Investments in Urbanized Areas Under 1 Million in Population



		Total New Boardings by 2030		
Average Annual Investment (Billions of 2010 Dollars)	Average Annual Percent Change vs. 2010	New Riders Supported (Billions of Annual Boardings)	Average Annual Growth in Boardings*	Funding Level Description
$2.6	9.9%	2.8	6.4%	
$1.5	5.1%	1.6	4.5%	
$1.0	1.4%	1.0	3.2%	Trend Growth in PMT (1995 to 2010)
$0.9	0.0%	0.9	2.8%	Maintain Spending (2010)
$0.5	-7.3%	0.5	1.6%	MPO Projected Growth
$0.3	-11.6%	0.3	1.3%	
$0.1	-68.0%	0.1	0.3%	

** As compared with total urban ridership in 2008; only includes increases covered by investments passing TERM's benefit-cost test.*

Source: Transit Economic Requirements Model.

CHAPTER 8

Selected Capital Investment Scenarios

Selected Highway Capital Investment Scenarios

This section presents future investment scenarios that build on the Chapter 7 analyses of alternative levels of future investment in highways and bridges. Each scenario includes projections for system conditions and performance based on simulations with the Highway Economic Requirements System (HERS) and National Bridge Investment Analysis System (NBIAS). To put the modeling results in perspective, each scenario scales up the total amount of simulated investment using ratio factors to add in the types of highway and bridge investment that are beyond these models' scopes. A subsequent section of this chapter explores transit investment scenarios that, like those of this section, start with a 2010 base year and cover the 20-year period through 2030. All the scenarios are intended to be illustrative; none of them is endorsed as a target level of funding.

Chapter 9 includes supplemental analyses relating to these scenarios, including comparisons with the investment levels presented for comparable scenarios in previous C&P reports. Chapter 10 includes a series of sensitivity analyses that explore the implications of alternative technical assumptions for the scenario investment levels. The Introduction to Part II provides critical background information relating to the technical limitations of the analysis, which are discussed further in the appendices.

Pursuant to Moving Ahead for Progress in the 21st Century (MAP-21), the National Highway System (NHS) will be expanded to include additional principal arterial and connector mileage that was not part of the original system. In light of this change, projecting future NHS investment needs over 20 years based on the system as it existed in 2010 would have limited value. Rather than dropping the NHS scenarios from the C&P report series until a formal NHS re-designation is completed, this report includes projections based on an estimate of what the system would ultimately look like by adding in principal arterials that are not currently part of the NHS. After the revised NHS designations have been coded into the HPMS and National Bridge Inventory (NBI), future editions of this report will use them for the NHS-based scenarios.

Scenarios Selected for Analysis

For the entire road network and then separately for Federal-aid highways, the NHS, and the Interstate Highway System, this section examines the four scenarios described in *Exhibit 8-1*. Each of these scenarios is based on capital investment by all levels of government combined. The question of what portion should be funded by the Federal government, State governments, local governments, or the private sector is beyond the scope of this report. Each scenario pairs an assumed level of total investment in the types of improvements modeled by HERS with an assumed level of investment in the types of improvements modeled by NBIAS; these levels are drawn from those considered in Chapter 7. Together, the scopes of these models cover spending on highway expansion and pavement improvements on Federal-aid highways (HERS) and on bridge rehabilitation on all highways (NBIAS). In the absence of data required for the non-modeled types of highway and bridge investment, each scenario simply assumes that their share of highway and bridge investment will remain at the 2010 percentage. Percent shares in 2010 also served to distribute the amount of non-modeled investment among the component categories: pavement spending on non-Federal-aid highways, system expansion spending on non-Federal-aid highways, and system enhancement spending (which include safety enhancements, operational improvements, and environmental projects).

Exhibit 8-1 Capital Investment Scenarios for Highways and Bridges, Derivation of Components

Scenario Component	Sustain 2010 Spending*	Maintain Conditions and Performance	Intermediate Improvement	Improve Conditions and Performance
HERS-Derived	Sustain spending on types of capital improvements modeled in HERS at 2010 levels in constant dollar terms over next 20 years	Set spending at the average of (1) the level at which projected average IRI in 2030 matches that in 2010, and (2) the level at which projected average delay per VMT in 2030 matches that in 2010	Set spending at the level sufficient to fund all potential projects with a BCR greater than or equal to 1.5	Set spending at the level sufficient to fund all cost-beneficial potential projects (i.e., those with a BCR greater than or equal to 1.0)
NBIAS-Derived	Sustain spending on types of capital improvements modeled in NBIAS at 2010 levels in constant dollar terms over the next 20 years	Set spending at the level at which the projected average bridge sufficiency rating in 2030 matches that in 2010	Set spending at the level which achieves one-half of the projected increase to the average bridge sufficiency rating under the **Improve Conditions and Performance** scenario	Set spending at the level sufficient to fund all cost-beneficial potential projects
Other (Non-Modeled)	Sustain spending on types of capital improvements not modeled in HERS or NBIAS at 2010 levels in constant dollar terms over the next 20 years	Set spending at the level necessary so that the nonmodeled share of total highway and bridge investment will remain the same as in 2010	Set spending at the level necessary so that the nonmodeled share of total highway and bridge investment will remain the same as in 2010	Set spending at the level necessary so that the nonmodeled share of total highway and bridge investment will remain the same as in 2010

** Highway capital spending in 2010 was supplemented by one-time funding under the Recovery Act.*

Q&A

How do the definitions of the selected scenarios presented in this report compare to those presented in the 2010 C&P Report?

The **Sustain 2010 Spending** scenario is defined in a manner consistent with the **Sustain Current Spending** scenario presented in previous editions of the C&P report; however, the scenario name was changed to emphasize that 2010 was an atypical year, since spending was boosted by one-time funding under the Recovery Act. The names and definitions of the **Improve Conditions and Performance** scenario and the **State of Good Repair** benchmark are unchanged.

The definition of the HERS-derived component of the **Intermediate Improvement** scenario remains unchanged. For the 2010 C&P Report, the NBIAS-derived component was defined around the average annual spending growth rate taken from the HERS-derived component; for this edition, the NBIAS-derived component has been redefined to be independent of HERS, and instead represents a level of investment that achieves half of the improvement in the average bridge sufficiency rating computed for the **Improve Conditions and Performance** scenario.

The **Maintain Conditions and Performance** scenario is similar in concept to the comparable scenario in the 2010 C&P Report, in that it attempts to maintain selected performance measures at their base-year levels through the end of the 20-year analysis period; however, the target measures have been modified. The NBIAS-derived component of the scenario targets the average bridge sufficiency rating rather than the bridge investment backlog, a measure that was utilized for the last several editions of the C&P report.

The HERS-derived component of the **Maintain Conditions and Performance** scenario had been defined around maintaining average highway user cost for several editions through the 2008 C&P Report. For technical reasons, it had become increasingly cumbersome to apply and explain this target measure, so in the 2010 C&P Report, average speed was adopted instead, in large part because it yielded similar results at the systemwide level (though this was not consistently true for subsets of the system). The HERS-derived component of this scenario used for the current edition is defined as the average of the investment level estimated to be sufficient to maintain average IRI, and the investment level estimated to be sufficient to maintain average delay. In practice, this approach results in one of these target measures improving somewhat over 20 years, while the other gets somewhat worse—an outcome consistent with the results obtained when the target measure was average highway user cost. At the systemwide level, and assuming that VMT growth conforms to HPMS forecasts, using average speed as the target measure as in the 2010 C&P Report would have produced annual average investment levels of $88.4 billion, or 2.5 percent more than what is shown in *Exhibit 8-2.*

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The projections for conditions and performance in each scenario represent estimates of what could be achieved with a given level of investment assuming an economically driven approach to project selection. They do not represent what would be achieved given current decision making practices. Consequently, comparing the relative conditions and performance outcomes across the different scenarios may be more illuminating than focusing on the specific projections for each individual scenario.

Scenario Spending Levels

Future spending levels by scenario, summarized in *Exhibit 8-2*, are stated in constant 2010 dollars. (Chapter 9 illustrates how to convert these real-dollar values into nominal [future dollar] values that factor in inflation beyond 2010.) The modeling on which the scenarios are based (which was presented in Chapter 7) assumes that spending grows at an annual percent rate that does not vary over the 20-year analysis period, but which differs between the types of investments modeled by HERS and those modeled by NBIAS, and also in some scenarios according to the assumed rate of future traffic growth. (The average annual investment levels are determined by summing the amounts expended for each year from 2011 through 2030 under the scenario, and dividing by 20.)

The application of the four illustrative scenarios to different highway systems produces the subscenarios in *Exhibit 8-2*. For example, the subscenario for Federal-aid highways in the **Sustain 2010 Spending** scenario fixes average annual spending on those highways at what was actually spent in 2010, $75.8 billion, without likewise forcing the portions of that spending directed to the NHS or the Interstate System to match their 2010 levels. Differences between these portions and the corresponding base-year amounts arise because HERS and NBIAS rely on benefit-cost principles to flexibly allocate spending among potential improvements within their scope.

For each of the other scenarios in *Exhibit 8-2*, the spending levels vary according to the future growth rate assumed for vehicle miles traveled (VMT). As discussed in Chapter 7, the VMT forecasts from the HPMS imply an average annual growth rate of 1.85 percent, whereas the 15-year trend growth (between 1995 and 2010) was only 1.36 percent. Assuming that future growth follows the trend rather than the forecast rate reduces the spending level associated with achieving scenario goals related to pavement improvements and system expansion, which are modeled with HERS. The needs for bridge rehabilitation spending are less sensitive to changes in VMT growth, so the implied traffic growth from the NBI forecasts was used to generate all of the NBIAS inputs to these scenarios.

The **Maintain Conditions and Performance** scenario is geared toward maintaining overall conditions and performance on the particular portion of the road network to which the scenario is being applied. For example, when the scenario relates to maintaining average conditions and performance on Federal-aid highways, it may entail improvement or deterioration in average conditions and performance on subsets of these highways, such as the Interstate Highway System. The models used to simulate the scenarios, HERS and NBIAS, are each designed to determine the investment program that will minimize the cost of achieving the scenario goal.

Spending Levels Assuming Forecast Growth in VMT

The **Maintain Conditions and Performance** scenario uses average pavement roughness, average delay per VMT, and average bridge sufficiency rating as the measures of overall system conditions and performance that it seeks to maintain. Although the system to which these goals pertain varies across the subscenarios, the average annual amount of investment is uniformly less than actual 2010 spending. A major reason for this pattern is that the 2010 level of investment was quite high by historical standards (due largely to the

Exhibit 8-2 Summary of Average Annual Investment Levels, by Scenario

Scenario and Comparison Parameter	Assuming Higher VMT Growth Derived from HPMS Forecasts[1] Interstate System	NHS[3]	Federal-Aid Highways	All Roads	Assuming Lower, Trend-Based VMT Growth[2] Federal-Aid Highways	All Roads
Sustain 2010 Spending Scenario[4]						
Average Annual Investment (Billions of 2010 Dollars), for 2011 through 2030	**$20.2**	**$53.9**	**$75.8**	**$100.2**	**$75.8**	**$100.2**
Maintain Conditions and Performance Scenario						
Average Annual Investment (Billions of 2010 Dollars), for 2011 Through 2030	**$17.4**	**$37.8**	**$67.3**	**$86.3**	**$50.3**	**$65.3**
Percent Difference Relative to 2010 Spending[4]	-14.1%	-29.8%	-11.2%	-13.9%	-33.6%	-34.8%
Annual Spending Increase Needed to Support Scenario Investment Level[5]	-1.47%	-3.51%	-1.15%	-1.44%	-4.08%	-4.29%
Intermediate Improvement Scenario						
Average Annual Investment (Billions of 2010 Dollars), for 2011 Through 2030	**$27.8**	**$58.8**	**$87.6**	**$111.9**	**$73.1**	**$93.9**
Percent Difference Relative to 2010 Spending[4]	37.8%	9.2%	15.6%	11.7%	-3.5%	-6.3%
Annual Spending Increase Needed to Support Scenario Investment Level[5]	2.96%	0.83%	1.36%	1.04%	-0.34%	-0.62%
Improve Conditions and Performance Scenario						
Average Annual Investment (Billions of 2010 Dollars), for 2011 through 2030	**$33.1**	**$74.9**	**$113.7**	**$145.9**	**$95.7**	**$123.7**
Percent Difference Relative to 2010 Spending[4]	64.0%	39.1%	50.1%	45.7%	26.4%	23.4%
Annual Spending Increase Needed to Support Scenario Investment Level[5]	4.51%	3.05%	3.72%	3.46%	2.18%	1.96%
State of Good Repair Benchmark[6]						
Average Annual Investment (Billions of 2010 Dollars), for 2011 Through 2030	**$13.2**	**$34.5**	**$60.4**	**$78.3**	**$57.2**	**$72.9**

[1] As discussed in Chapter 7, the "forecast" VMT growth derived from the HPMS comes out to an average annual growth rate of 1.85 percent. HERS assumes this represents the VMT that would occur at a constant price, but adjusts the growth for individual scenarios in response to changes in user costs. NBIAS is less sensitive to changes in VMT growth, and the implied traffic growth from the NBI was used to generate all of the NBIAS inputs to these scenarios.

[2] As discussed in Chapter 7, the average annual growth rate for the 15-year period from 1995 to 2010 was 1.36 percent, and is referenced as the "Trend" VMT growth. HERS assumes this represents the VMT that would occur at a constant price, and adjusts the growth rate for the individual scenarios in response to changes in highway user costs. NBIAS is less sensitive to changes in VMT growth, and the implied traffic growth from the NBI was used to generate all of the NBIAS inputs to these scenarios.

[3] The NHS statistics presented in this chapter are intended to approximate the NHS as it will exist after its expansion directed by MAP-21, not the NHS as it existed in 2010.

[4] Highway capital spending in 2010 was boosted by one-time funding under the Recovery Act.

[5] This percentage represents the annual percent change for each year relative to 2010 that would be required to achieve the average annual funding level specified for the scenario in constant dollar terms. Additional increases in nominal dollar terms would be needed to offset the impact of future inflation. Negative values indicate that the average annual investment level associated with the scenario is lower than 2010 spending.

[6] The State of Good Repair benchmark is the subset of the Improve Conditions and Performance scenario that pertains to system rehabilitation investments only, and excludes investments in system expansion and system enhancement.

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

Recovery Act), particularly for system rehabilitation spending. (For a discussion of highway and bridge investment trends, see Chapter 6). Highway capital spending increased by 10.8 percent between 2008 and 2010 in nominal dollar terms while highway construction costs dropped by 18.0 percent. Factoring in this price change, capital spending grew by 35.1 percent in constant dollar terms between 2008 and 2010.

For the version of the **Maintain Conditions and Performance** scenario focused on all roads (and assuming HPMS forecast VMT growth), the average annual investment level of $86.3 billion is 13.9 percent lower than actual 2010 capital spending of $100.2 billion on all roads; the goals of this subscenario could be achieved even if capital spending declined by 1.44 percent per year over 20 years in constant dollar terms. Similar percentage differences are evident in the subscenarios for Federal-aid highways (11.2 percent) and Interstate highways (14.1 percent). The outlier is the sub-scenario for the NHS, where the level of investment to maintain conditions and performance is estimated to be 29.8 percent lower than the amount of investment directed to that system in 2010. Because the Interstate highways form a significant portion of the NHS, this implies relatively sharp reductions in spending for the remaining portion off of the Interstate System. Annual percentage growth rates in spending are between -1.0 percent and -1.5 percent across subscenarios, except for the -3.5 percent annual decline in spending indicated to be consistent with maintaining overall conditions and performance on the NHS. It is important to note that because 2010 highway capital spending included one-time funding under the Recovery Act, sustaining this level of investment in the future would present a greater challenge than would be the case for a more typical base year.

Unless one is completely satisfied with base year conditions and performance, investing at a level projected to maintain that level of performance would not yield an ideal result. The analyses reflected in the **Improve Conditions and Performance** scenario suggest that an economically driven approach to investment that funds all cost-beneficial improvements would substantially increase real spending on highways and bridges above base-year levels. Assuming forecast VMT growth for the 2011–2030 analysis period, the annual percent increase in investment associated with implementation of all cost-beneficial capital improvements is 4.51 percent for the Interstate highways, 3.05 percent for the NHS, 3.72 percent for Federal-aid highways, and 3.46 percent for all roads. The associated levels of average annual spending represent an investment ceiling above which it would not be cost-beneficial to invest even if available funding were unlimited, and exceed the 2010 levels by 64.0 percent for Interstate highways, 39.1 percent for the NHS, 50.1 percent for Federal-aid highways, and 45.7 percent for all roads. For all roads, the average annual spending amounts to fully implement all cost-beneficial investments is estimated to be $145.9 billion, or $2.9 trillion over the 20-year period, stated in constant 2010 dollars.

The State of Good Repair benchmark represents the portion of average annual spending that the **Improve Conditions and Performance** scenario allocates to system rehabilitation investments. Put at $78.3 billion in *Exhibit 8-2* for all roads, this benchmark represents the amount of cost-beneficial investment identified

Q&A

Does the State of Good Repair benchmark apply the same criteria for all types of roadways modeled in HERS?

No. For principal arterials, the deficiency levels in HERS have been set so that the model will consider taking action on a pavement only when its International Roughness Index (IRI) value has risen above 95 (inches per mile), meaning that it would no longer be considered to have "good" ride quality based on the criteria described in Chapter 3.

For roads functionally classified as collectors, the HERS deficiency levels have been set so that pavement actions will only be considered when IRI values have risen above 170, and the roads, thus, no longer meet the criteria for "acceptable" ride quality. The IRI threshold for minor arterials is set at 120.

Although the engineering thresholds identified above define when the model may consider a pavement improvement, any such improvement must pass a benefit-cost test in order to be implemented. Even when HERS is given an unlimited budget to work with, it does not recommend improving all principal arterials to the "good" ride quality level, or all collectors to the "acceptable" ride quality level. The specific IRI value at which a pavement improvement will pass a benefit-cost test depends on a number of factors, including the traffic volume and average speeds on that facility. As discussed in Chapter 3, pavement ride quality has a greater impact on highway user costs on higher-speed roads.

for rehabilitation of existing pavements and bridges. In determining the size of this benchmark, HERS and NBIAS screen out through benefit-cost analysis any assets that may have outlived their original purpose, rather than automatically re-investing in all assets in perpetuity. With national consensus lacking on exactly what constitutes a "state of good repair" for the various transportation assets, alternative benchmarks with different objectives could be equally valid from a technical perspective.

The goal of the **Intermediate Improvement** scenario is to partially achieve the performance improvements associated with the economically driven approach to investment taken in the **Improve Conditions and Performance** scenario. For bridge rehabilitation spending, the **Intermediate Improvement** scenario seeks to achieve half of the improvement in the average bridge sufficiency rating; for spending on pavement rehabilitation and highway expansion, the scenario implements all projects with a benefit-cost ratio (BCR) of 1.5 or greater, as opposed to 1.0 or greater in the **Improve Conditions and Performance** scenario. (Applying a minimum BCR cutoff higher than 1.0 reduces the risk of investing in projects that initially appear cost beneficial but do not prove so due to unexpected changes in future costs or travel demand.) Assuming forecast VMT growth for 2011–2030, the average annual spending in the **Intermediate Improvement** scenario for all roads, $111.9 billion, exceeds the actual 2010 level by $11.7 billion, which is about one-fourth of the $45.7 billion increase indicated in the **Improve Conditions and Performance** scenario**.** For the Federal-aid highways and the NHS, the corresponding proportion is similar to that for all roads, but, for the Interstate System, the increase in spending relative to 2010 under the **Intermediate Improvement** scenario amounts to nearly three-fifths of the increase under the **Improve Conditions and Performance** scenario.

Spending Levels Assuming Trend Growth in VMT

Replacing the overall rate of traffic growth implied by the HPMS forecasts with the 15-year historic trend rate of growth reduces the scenario levels of spending substantially. Annual spending in the **Maintain Conditions and Performance** scenario averages $65.3 billion for all roads and $50.3 billion for Federal-aid highways, which are each about 25 percent lower than when the overall rate of VMT growth from the HMPS forecasts was used. For the **Intermediate Improvement** and **Improve Conditions and Performance** scenarios, the spending reductions from the forecast growth case are smaller, at about 16 percent. The results for annual percent growth in spending show spending decreasing at just over 4 percent per year in the **Maintain Conditions and Performance** scenario, and at less than one percent in the **Intermediate Improvement** scenario. Only in the **Improve Conditions and Performance** scenario does spending increase, at about 2 percent per year, when trend growth in traffic is assumed.

Scenario Spending Patterns and Conditions and Performance Projections

The following discussion details the derivation of scenario spending levels, the patterns in spending by type of improvement and highway functional class, and the projections for conditions and performance.

Systemwide Scenarios

For the scenarios that consider all roads, the derivation of the average annual investment levels is presented in *Exhibit 8-3* (forecast-based VMT growth) and *Exhibit 8-4* (trend-based VMT growth). The HERS-derived component, which accounts in each scenario for most of the total investment, represents spending on pavement rehabilitation and capacity expansion on Federal-aid highways. The NBIAS-derived component represents rehabilitation spending on all bridges, including those not on the Federal-aid highways. In the **Sustain 2010 Spending** scenario, the values for these components sum to $72.5 billion, of which $56.4 billion is the HERS-derived component. Nonmodeled spending accounted in 2010 for 26.6 percent

Exhibit 8-3 Systemwide Highway Capital Investment Scenarios for 2011 through 2030: Derivation and Distribution

	Sustain 2010 Spending Scenario	Maintain Conditions & Performance Scenario	Intermediate Improvement Scenario	Improve Conditions & Performance Scenario
Scenario Derivation, by Input Components*				
Average Annual Investment (Billions of 2010 Dollars)	**$100.2**	**$86.3**	**$111.9**	**$145.9**
HERS-Derived Component (Billions of 2010 Dollars)	$56.4	$51.1	$67.8	$86.9
Percent of Scenario Derived from HERS	56.3%	59.2%	60.6%	59.5%
Annual Percent Change in HERS Spending	0.0%	-1.0%	1.7%	4.0%
Minimum BCR for HERS-Derived Component	1.92	2.17	1.50	1.00
NBIAS-Derived Component (Billions of 2010 Dollars)	$17.1	$12.2	$14.3	$20.2
Percent of Scenario Derived from NBIAS	17.0%	14.1%	12.8%	13.8%
Annual Percent in NBIAS Spending	0.0%	-3.3%	-1.7%	1.6%
Other Component (Billions of 2010 Dollars)	$26.7	$23.0	$29.8	$38.8
Percent of Scenario Derived from Other	26.6%	26.6%	26.6%	26.6%
Distribution by Capital Improvement Type, Average Annual (Billions of 2010 Dollars)				
System Rehabilitation-Highway	$40.4	$36.5	$46.5	$58.1
System Rehabilitation-Bridge	$17.1	$12.2	$14.3	$20.2
System Rehabilitation-Total	$57.4	$48.7	$60.8	$78.3
System Expansion	$30.0	$26.6	$36.8	$49.0
System Enhancement	$12.8	$11.0	$14.3	$18.6
Total, All Improvement Types	**$100.2**	**$86.3**	**$111.9**	**$145.9**
Percent Distribution by Capital Improvement Type				
System Rehabilitation	57.3%	56.5%	54.4%	53.7%
System Expansion	29.9%	30.8%	32.9%	33.6%
System Enhancement	12.8%	12.8%	12.8%	12.8%

** Each scenario consists of three separately estimated components. The HERS-derived scenario components are linked directly to the analyses presented in* Exhibits 7-3 *through* 7-11 *in Chapter 7 that assumed future VMT consistent with HPMS forecasts; the NBIAS-derived components are linked directly to the analysis presented in* Exhibit 7-16. *These components can be cross-referenced to those exhibits using the annual percent change in HERS spending or NBIAS spending reflected in this table. The third scenario component, identified as "Other," represents types of capital spending beyond those modeled in HERS or NBIAS; each scenario assumes that the percentage of total spending on these items in the future will remain the same as in 2010.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

of total investment ($26.7 billion out of $100.2 billion) and is assumed to form the same share in all scenarios. The non-modeled spending is allocated among types of capital improvements according to its 2010 percent distribution: 36.7 percent, system rehabilitation (non-Federal-aid highways); 15.4 percent, system expansion (non-Federal-aid highways), and 47.9 percent, system enhancements. Because they include non-modeled spending, the amounts shown in any scenario for the "system rehabilitation-highway" and "system expansion" categories sum to more than the HERS-derived component of spending.

The minimum BCR associated with the HERS components of the **Improve Conditions and Performance** scenario (1.0) and the **Intermediate Improvement** scenario (1.5) are the same whether forecast VMT growth or trend-based VMT growth is assumed, as these scenarios are defined around these particular BCR levels. For the **Sustain 2010 Spending** scenario, the minimum BCR of 1.92 assuming forecast VMT growth (*Exhibit 8-3*) is higher than the minimum BCR of 1.42 assuming trend-based VMT growth (*Exhibit 8-4*) because higher future travel volumes would tend to increase the benefits associated with both pavement and

Exhibit 8-4 Systemwide Highway Capital Investment Scenarios for 2011 through 2030: Derivation and Distribution, Assuming Lower Trend-Based VMT Growth

	Sustain 2010 Spending Scenario	Maintain Conditions & Performance Scenario	Intermediate Improvement Scenario	Improve Conditions & Performance Scenario
Scenario Derivation, by Input Components*				
Average Annual Investment (Billions of 2010 Dollars)	**$100.2**	**$65.3**	**$93.9**	**$123.7**
HERS-Derived Component (Billions of 2010 Dollars)	$56.4	$35.7	$54.6	$70.5
Percent of Scenario Derived from HERS	56.3%	54.7%	58.1%	57.1%
Annual Percent Change in HERS Spending	0.0%	-4.6%	-0.3%	2.1%
Minimum BCR for HERS-Derived Component	1.42	2.53	1.50	1.00
NBIAS-Derived Component (Billions of 2010 Dollars)	$17.1	$12.2	$14.3	$20.2
Percent of Scenario Derived from NBIAS	17.0%	18.7%	15.3%	16.3%
Annual Percent in NBIAS Spending	0.0%	-3.3%	-1.7%	1.6%
Other Component (Billions of 2010 Dollars)	$26.7	$17.4	$25.0	$32.9
Percent of Scenario Derived from Other	26.6%	26.6%	26.6%	26.6%
Distribution by Capital Improvement Type, Average Annual (Billions of 2010 Dollars)				
System Rehabilitation-Highway	$43.4	$29.0	$41.8	$52.7
System Rehabilitation-Bridge	$17.1	$12.2	$14.3	$20.2
System Rehabilitation-Total	$60.4	$41.2	$56.1	$72.9
System Expansion	$26.9	$15.8	$25.8	$35.0
System Enhancement	$12.8	$8.3	$12.0	$15.8
Total, All Improvement Types	**$100.2**	**$65.3**	**$93.9**	**$123.7**
Percent Distribution by Capital Improvement Type				
System Rehabilitation	60.3%	63.1%	59.8%	58.9%
System Expansion	26.9%	24.1%	27.5%	28.3%
System Enhancement	12.8%	12.8%	12.8%	12.8%

** Each scenario consists of three separately estimated components. The HERS-derived scenario components are linked directly to the analyses presented in* Exhibits 7-3 through 7-11 *in Chapter 7 that assumed future VMT consistent with the 15-year trend from 1995 to 2010; the NBIAS-derived components are linked directly to the analysis presented in* Exhibit 7-16. *These components can be cross-referenced to those exhibits using the annual percent change in HERS spending or NBIAS spending reflected in this table. The third scenario component, identified as "Other," represents types of capital spending beyond those modeled in HERS or NBIAS; each scenario assumes that the percentage of total spending on these items in the future will remain the same as in 2010.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

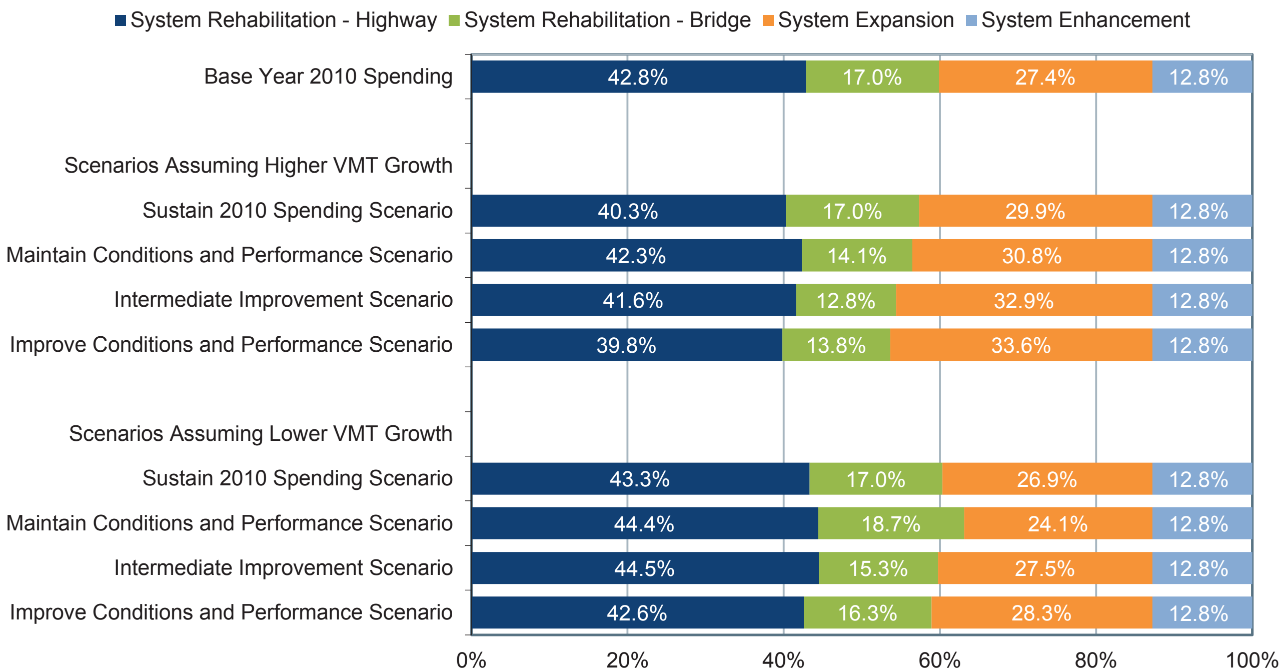
capacity improvements. For the **Maintain Conditions and Performance** scenario, the minimum BCR of 2.17 assuming forecast VMT growth is higher than the minimum BCR of 1.42 assuming trend-based VMT growth primarily because the average annual investment level associated with achieving the goals of this scenario is considerably higher assuming forecast VMT growth, so HERS would need to move further down its BCR-prioritized list of potential improvements.

Spending by Improvement Type

In the **Improve Conditions and Performance** scenario, annual spending on highway and bridge rehabilitation averages $78.3 billion assuming forecast VMT growth and $72.9 billion assuming trend VMT growth, in either case considerably more than the $60.0 billion of such spending in 2010 identified in Chapter 6. This suggests that achieving a state of good repair on the Nation's highways would require either a significant increase in overall highway and bridge investment or a significant redirection of investment from other types of improvements toward system rehabilitation.

Exhibit 8-5 compares the distributions from the preceding two exhibits for investment spending by improvement type with the actual distribution of capital spending in 2010. When higher VMT growth is assumed (based on HPMS forecast), system expansion comprises between 29.9 percent and 33.6 percent of each scenario's total investment in highways and bridges, somewhat higher than its actual 27.4 percent share of such spending in 2010. The share of spending directed to rehabilitation is correspondingly lower

Exhibit 8-5 Systemwide Highway Capital Investment Scenarios for 2011 Through 2030: Distribution by Capital Improvement Type Compared to 2010 Spending



Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

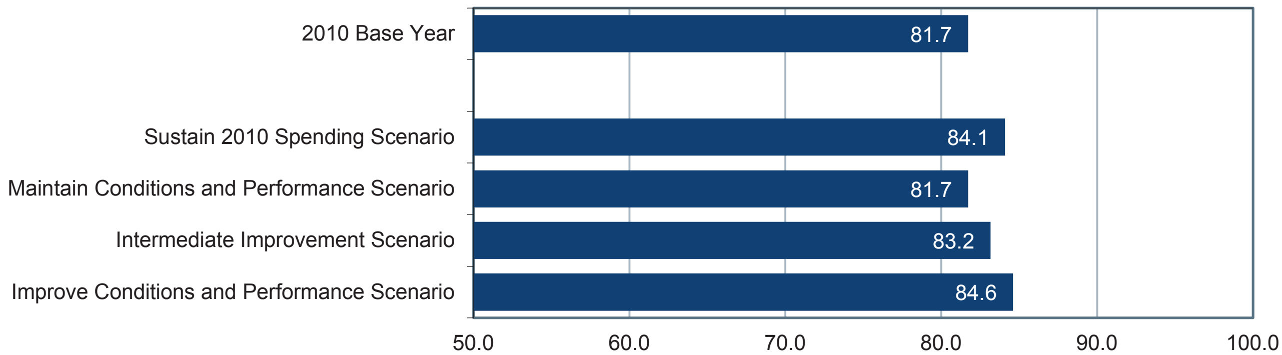
in each scenario than it was in 2010; the sharpest decline is indicated for bridge rehabilitation spending, which attracts only 13.1 percent of spending in the **Improve Conditions and Performance** scenario versus 17.0 percent in 2010.

When lower VMT growth is assumed (based on the 15-year historic trend), compared with its actual 27.4 percent share in 2010, the system expansion share of spending is virtually the same in the **Intermediate Improvement** scenario, 3.3 percentage points lower in the **Sustain 2010 Spending** scenario, and marginally higher or lower in the other scenarios. In each scenario, the system expansion share of spending assuming trend-based VMT growth is lower than where a higher VMT growth rate is assumed—in the **Improve Conditions and Performance** scenario, for example, 28.3 percent versus 33.6 percent. This reflects that benefits from system expansion projects tend to be more sensitive to future traffic volumes than benefits from system rehabilitation projects.

Projections for 2030 Conditions and Performance

Since the HERS model considers only Federal-aid highways, whereas NBIAS considers bridges on all roads, the only conditions and performance indicators available for the systemwide scenarios are those for bridges. *Exhibit 8-6* presents projections for the average bridge sufficiency index . Apart from the **Maintain Conditions and Performance** scenario, the values of this index projected for 2030 indicate improvement on the 2010 base year values. The largest improvement is in the **Improve Conditions and Performance**

Exhibit 8-6 Projected Impact of Systemwide Capital Investment Scenarios on Average Bridge Sufficiency Rating in 2030



Source: National Bridge Investment Analysis System.

scenario, where spending on bridge rehabilitation is at the highest level considered and the average sufficiency index is projected to be 84.6 in 2030 compared with 81.7 in 2010.

Federal-Aid Highway Scenarios

For the scenarios that focus on Federal-aid highways, the average annual investment totals are derived in *Exhibit 8-7* (forecast-based VMT growth) and *Exhibit 8-8* (trend-based VMT growth). The NBIAS-derived components are smaller than in the corresponding systemwide scenarios (compare with *Exhibit 8-3* and *Exhibit 8-4*) because they exclude spending on types of roads generally ineligible for Federal aid—local roads and rural minor collectors. Bridge rehabilitation spending on such roads is excluded in these scenarios, even though the bridges themselves are eligible for Federal aid. On the other hand, the HERS-derived components of the Federal-aid highway scenarios are the same as in the systemwide scenarios because the scope of HERS is limited to Federal-aid highways. The systemwide scenarios added an allowance for nonmodeled spending on pavement rehabilitation and system expansion on highways ineligible for Federal aid, but restricting the scenario focus to Federal-aid highways eliminates the need for such adjustment. The only nonmodeled spending in the Federal-aid highway scenarios is on system enhancements, which accounted for 9.0 percent of investment in Federal-aid highways in 2010.

Under the **Sustain 2010 Spending** scenario, highway rehabilitation and system expansion (the HERS-derived component) accounted for 74.5 percent of the total, matching their combined share of 2010 spending. Bridge rehabilitation (the NBIAS-derived component) accounted for 16.5 percent of the investment under this scenario, also matching its share of 2010 spending. As shown in *Exhibit 8-7*, assuming forecast-based VMT growth, average International Roughness Index (IRI) is projected to be reduced (i.e., to improve) by 11.5 percent, while average delay per VMT increases (worsens) by 1.9 percent. As shown in *Exhibit 8-8*, assuming trend-based VMT growth, both average IRI and average delay are projected to be reduced, by 17.7 percent and 7.8 percent, respectively.

Although the **Maintain Conditions and Performance** scenario is geared toward conditions and performance in 2030 being the same as in 2010 overall, it does not force each individual indicator of conditions and performance to remain at its 2010 level. Assuming forecast-based VMT growth, average pavement roughness is projected to be 7.6 percent lower in 2030 than in 2010 under this scenario and for average delay per VMT to be 4.3 percent higher (*Exhibit 8-7*). Only in the two scenarios geared toward improving conditions and performance are both average pavement roughness and average delay projected to be lower in 2030 than in 2010. Under the **Improve Conditions and Performance** scenario, the projected declines are 26.7 percent and 8.0 percent, respectively. The patterns in the bridge performance indicators are very similar to those found in the systemwide projections discussed above.

Exhibit 8-7 Federal-Aid Highway Capital Investment Scenarios for 2011 through 2030: Derivation, Distribution, and Projected Impacts

	Sustain 2010 Spending Scenario	Maintain Conditions & Performance Scenario	Intermediate Improvement Scenario	Improve Conditions & Performance Scenario
Scenario Derivation, by Input Components[1]				
Average Annual Investment (Billions of 2010 Dollars)	**$75.8**	**$67.3**	**$87.6**	**$113.7**
HERS-Derived Component (Billions of 2010 Dollars)	$56.4	$51.1	$67.8	$86.9
Percent of Scenario Derived from HERS	74.5%	76.0%	77.4%	76.4%
Annual Percent Change in HERS Spending	0.0%	-1.0%	1.7%	4.0%
Minimum BCR for HERS-Derived Component	1.92	2.17	1.50	1.00
NBIAS-Derived Component (Billions of 2010 Dollars)	$12.5	$10.1	$12.0	$16.6
Percent of Scenario Derived from NBIAS	16.5%	15.0%	13.6%	14.6%
Annual Percent in NBIAS Spending	0.0%	-2.1%	-0.4%	2.6%
Other Component (Billions of 2010 Dollars)	$6.8	$6.1	$7.9	$10.2
Percent of Scenario Derived from Other	9.0%	9.0%	9.0%	9.0%
Distribution by Capital Improvement Type, Average Annual (Billions of 2010 Dollars)				
System Rehabilitation-Highway	$30.6	$28.1	$35.6	$43.9
System Rehabilitation-Bridge	$12.5	$10.1	$12.0	$16.6
System Rehabilitation-Total	$43.1	$38.2	$47.5	$60.4
System Expansion	$25.9	$23.0	$32.2	$43.0
System Enhancement	$6.8	$6.1	$7.9	$10.2
Total, All Improvement Types	**$75.8**	**$67.3**	**$87.6**	**$113.7**
Percent Distribution by Capital Improvement Type				
System Rehabilitation	56.9%	56.8%	54.3%	53.2%
System Expansion	34.1%	34.2%	36.7%	37.8%
System Enhancement	9.0%	9.0%	9.0%	9.0%
Projected 2030 Values for Selected Indicators				
Average Bridge Sufficiency Rating	83.6	82.0	83.3	84.7
Percent of VMT on Roads with Good Ride Quality	64.7%	62.1%	69.5%	75.8%
Percent of VMT on Roads with Acceptable Ride Quality	88.1%	86.7%	90.4%	93.4%
Projected Changes by 2030 Relative to 2010 for Selected Indicators				
Percent Change in Average IRI[2]	-11.5%	-7.6%	-18.0%	-26.7%
Percent Change in Average Delay	1.9%	4.3%	-2.4%	-8.0%

[1] Each scenario consists of three separately estimated components. The HERS-derived scenario components are linked directly to the analyses presented in Exhibits 7-3 *through* 7-11 *in Chapter 7 that assumed future VMT consistent with HPMS forecasts; the NBIAS-derived components are linked directly to the analysis presented in* Exhibit 7-17. *These components can be cross-referenced to those exhibits using the annual percent change in HERS spending or NBIAS spending reflected in this table. The third scenario component, identified as "Other," represents types of capital spending beyond those modeled in HERS or NBIAS; each scenario assumes that the percentage of total spending on these items in the future will remain the same as in 2010.*

[2] Reductions in average pavement roughness (IRI) translate into improved ride quality.

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

As shown in *Exhibit 8-8*, assuming trend-based VMT growth under the **Maintain Conditions and Performance** scenario for Federal-aid highways, average IRI and average delay would both remain unchanged in 2030 relative to 2010. This is a coincidence rather than an outcome forced by the scenario definition; it is simply the case that the mix of investments identified by HERS as having a BCR of 2.53 or higher just so happens to result in average IRI and average delay both being maintained. Ordinarily, based on the scenario definition, one would expect that one of these indicators would improve a little, while the

Exhibit 8-8 Federal-Aid Highway Capital Investment Scenarios for 2011 through 2030: Derivation, Distribution, and Projected Impacts, Assuming Lower Trend-Based VMT Growth

	Sustain 2010 Spending Scenario	Maintain Conditions & Performance Scenario	Intermediate Improvement Scenario	Improve Conditions & Performance Scenario
Scenario Derivation, by Input Components[1]				
Average Annual Investment (Billions of 2010 Dollars)	**$75.8**	**$50.3**	**$73.1**	**$95.7**
HERS-Derived Component (Billions of 2010 Dollars)	$56.4	$35.7	$54.6	$70.5
Percent of Scenario Derived from HERS	74.5%	70.9%	74.7%	73.7%
Annual Percent Change in HERS Spending	0.0%	-4.6%	-0.3%	2.1%
Minimum BCR for HERS-Derived Component	1.42	2.53	1.50	1.00
NBIAS-Derived Component (Billions of 2010 Dollars)	$12.5	$10.1	$12.0	$16.6
Percent of Scenario Derived from NBIAS	16.5%	20.1%	16.3%	17.3%
Annual Percent in NBIAS Spending	0.0%	-2.1%	-0.4%	2.6%
Other Component (Billions of 2010 Dollars)	$6.8	$4.5	$6.6	$8.6
Percent of Scenario Derived from Other	9.0%	9.0%	9.0%	9.0%
Distribution by Capital Improvement Type, Average Annual (Billions of 2010 Dollars)				
System Rehabilitation-Highway	$33.6	$22.6	$32.6	$40.6
System Rehabilitation-Bridge	$12.5	$10.1	$12.0	$16.6
System Rehabilitation-Total	$46.1	$32.7	$44.6	$57.2
System Expansion	$22.8	$13.1	$22.0	$30.0
System Enhancement	$6.8	$4.5	$6.6	$8.6
Total, All Improvement Types	**$75.8**	**$50.3**	**$73.1**	**$95.7**
Percent Distribution by Capital Improvement Type				
System Rehabilitation	60.9%	65.0%	61.0%	59.7%
System Expansion	30.2%	26.0%	30.0%	31.3%
System Enhancement	9.0%	9.0%	9.0%	9.0%
Projected 2030 Values for Selected Indicators				
Average Bridge Sufficiency Rating	83.6	82.0	83.3	84.7
Percent of VMT on Roads with Good Ride Quality	69.2%	55.8%	68.3%	74.8%
Percent of VMT on Roads with Acceptable Ride Quality	90.3%	84.0%	89.9%	93.1%
Projected Changes by 2030 Relative to 2010 for Selected Indicators				
Percent Change in Average IRI[2]	-17.7%	0.0%	-16.5%	-25.1%
Percent Change in Average Delay	-7.8%	0.0%	-7.3%	-12.1%

[1] *Each scenario consists of three separately estimated components. The HERS-derived scenario components are linked directly to the analyses presented in* Exhibits 7-3 *through* 7-11 *in Chapter 7 that assumed future VMT consistent with the 15-year trend from 1995 to 2010; the NBIAS-derived components are linked directly to the analysis presented in* Exhibit 7-16. *These components can be cross-referenced to those exhibits using the annual percent change in HERS spending or NBIAS spending reflected in this table. The third scenario component, identified as "Other," represents types of capital spending beyond those modeled in HERS or NBIAS; each scenario assumes that the percentage of total spending on these items in the future will remain the same as in 2010.*

[2] *Reductions in average pavement roughness (IRI) translate into improved ride quality.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

other would worsen a little. Under the **Improve Conditions and Performance** scenario assuming trend-based VMT growth, the projected reductions in average IRI and average delay per VMT are 25.1 percent and 12.1 percent, respectively.

Spending by Improvement Type and Highway Functional Class

As in the systemwide scenarios, basing the average rate of VMT growth on trend rather than the HPMS forecasts increases the rehabilitation share of spending in each Federal-aid highway scenario. The share ranges

from 53.2 percent in the **Improve Conditions and Performance** scenario when forecast growth is assumed (*Exhibit 8-7*) to 65.0 percent in the **Maintain Conditions and Performance** scenario when trend growth is assumed (*Exhibit 8-8*).

For the forecast VMT growth case, the next four exhibits add highway functional class to the breakdown of Federal-aid highway spending; *Exhibit 8-9*, *Exhibit 8-10*, *Exhibit 8-11*, and *Exhibit 8-12* present the distribution by improvement type and highway functional class for the **Sustain 2010 Spending** scenario,

Exhibit 8-9 Sustain 2010 Spending Scenario for Federal-Aid Highways: Distribution of Average Annual Investment for 2011 Through 2030 Compared With Actual 2010 Spending, by Functional Class and Improvement Type

Average Annual National Investment on Federal-Aid Highways (Billions of 2010 Dollars)						
	System Rehabilitation			System	System	
Functional Class	Highway	Bridge	Total	Expansion	Enhancement	Total
Rural Arterials and Major Collectors						
Interstate	$1.6	$0.9	$2.5	$1.2	$0.4	$4.1
Other Principal Arterial	$1.8	$0.8	$2.6	$0.6	$0.7	$3.9
Minor Arterial	$1.9	$0.7	$2.7	$0.3	$0.6	$3.6
Major Collector	$2.7	$1.1	$3.9	$0.3	$0.4	$4.6
Subtotal	**$8.1**	**$3.5**	**$11.6**	**$2.4**	**$2.2**	**$16.1**
Urban Arterials and Collectors						
Interstate	$5.4	$3.0	$8.4	$10.9	$1.0	$20.3
Other Freeway and Expressway	$2.7	$1.2	$3.9	$4.8	$0.7	$9.3
Other Principal Arterial	$5.7	$2.2	$7.9	$3.5	$1.5	$12.9
Minor Arterial	$6.0	$1.9	$7.9	$2.9	$0.9	$11.8
Collector	$2.7	$0.7	$3.4	$1.4	$0.6	$5.4
Subtotal	**$22.5**	**$9.0**	**$31.5**	**$23.5**	**$4.7**	**$59.6**
Total, Federal-Aid Highways*	**$30.6**	**$12.5**	**$43.1**	**$25.9**	**$6.8**	**$75.8**

Percent Above Actual 2010 Capital Spending on Federal-Aid Highways by All Levels of Government Combined						
	System Rehabilitation			System	System	
Functional Class	Highway	Bridge	Total	Expansion	Enhancement	Total
Rural Arterials and Major Collectors						
Interstate	-65.1%	29.7%	-52.7%	-12.2%	0.0%	-41.5%
Other Principal Arterial	-58.0%	-13.9%	-50.5%	-85.9%	0.0%	-62.1%
Minor Arterial	-49.3%	-6.3%	-42.1%	-82.4%	0.0%	-48.3%
Major Collector	-11.1%	14.8%	-4.9%	-73.3%	0.0%	-18.2%
Subtotal	**-48.8%**	**5.2%**	**-39.4%**	**-71.8%**	**0.0%**	**-45.8%**
Urban Arterials and Collectors						
Interstate	11.5%	-13.2%	1.3%	174.1%	0.0%	53.2%
Other Freeway and Expressway	36.8%	98.3%	51.3%	132.8%	0.0%	76.2%
Other Principal Arterial	20.0%	-20.6%	5.1%	-31.4%	0.0%	-8.7%
Minor Arterial	68.1%	41.6%	60.8%	26.9%	0.0%	44.2%
Collector	22.7%	-30.8%	5.8%	0.3%	0.0%	3.7%
Subtotal	**29.7%**	**-1.9%**	**18.8%**	**58.3%**	**0.0%**	**29.6%**
Total, Federal-Aid Highways*	**-7.7%**	**0.0%**	**-5.6%**	**11.0%**	**0.0%**	**0.0%**

** The term "Federal-Aid Highways" refers to those portions of the road network that are generally eligible for Federal funding. Roads functionally classified as rural minor collectors, rural local, and urban local are excluded, although some types of Federal program funds can be used on such facilities.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

the **Maintain Conditions and Performance** scenario, the **Intermediate Improvement** scenario, and the **Improve Conditions and Performance** scenario, respectively.

Moving to a finer level of detail tends to reduce the reliability of simulation results from HERS and NBIAS, so the results presented in these exhibits should be viewed with caution. It should also be noted that comparing scenario results with actual spending for the single year 2010 may result in some apparent anomalies that are primarily attributable to atypical spending patterns for that year influenced in part by the Recovery Act, rather than to the model results. Nevertheless, the patterns are strongly suggestive of

Exhibit 8-10 Maintain Conditions and Performance Scenario for Federal-Aid Highways: Distribution of Average Annual Investment for 2011 Through 2030 Compared With Actual 2010 Spending, by Functional Class and Improvement Type

Average Annual National Investment on Federal-Aid Highways (Billions of 2010 Dollars)						
	System Rehabilitation			System	System	
Functional Class	Highway	Bridge	Total	Expansion	Enhancement	Total
Rural Arterials and Major Collectors						
Interstate	$1.5	$0.7	$2.2	$1.1	$0.4	$3.8
Other Principal Arterial	$1.7	$0.7	$2.4	$0.6	$0.6	$3.5
Minor Arterial	$1.7	$0.6	$2.4	$0.3	$0.5	$3.2
Major Collector	$2.4	$1.0	$3.3	$0.2	$0.4	$4.0
Subtotal	**$7.3**	**$3.0**	**$10.3**	**$2.2**	**$1.9**	**$14.4**
Urban Arterials and Collectors						
Interstate	$5.1	$2.4	$7.6	$9.8	$0.9	$18.2
Other Freeway and Expressway	$2.5	$1.1	$3.6	$4.3	$0.6	$8.5
Other Principal Arterial	$5.1	$1.7	$6.8	$3.1	$1.4	$11.2
Minor Arterial	$5.6	$1.4	$7.0	$2.5	$0.8	$10.3
Collector	$2.4	$0.5	$3.0	$1.2	$0.5	$4.7
Subtotal	**$20.8**	**$7.1**	**$27.9**	**$20.8**	**$4.1**	**$52.8**
Total, Federal-Aid Highways*	**$28.1**	**$10.1**	**$38.2**	**$23.0**	**$6.1**	**$67.3**

Percent Above Actual 2010 Capital Spending on Federal-Aid Highways by All Levels of Government Combined						
	System Rehabilitation			System	System	
Functional Class	Highway	Bridge	Total	Expansion	Enhancement	Total
Rural Arterials and Major Collectors						
Interstate	-66.5%	4.9%	-57.1%	-14.8%	-11.2%	-46.0%
Other Principal Arterial	-62.2%	-20.2%	-55.1%	-86.9%	-11.2%	-65.6%
Minor Arterial	-54.6%	-17.9%	-48.5%	-84.8%	-11.2%	-54.1%
Major Collector	-23.2%	1.3%	-17.3%	-80.2%	-11.2%	-29.4%
Subtotal	**-54.0%**	**-8.2%**	**-46.0%**	**-74.1%**	**-11.2%**	**-51.5%**
Urban Arterials and Collectors						
Interstate	5.5%	-29.1%	-8.9%	145.7%	-11.2%	37.4%
Other Freeway and Expressway	27.8%	73.0%	38.5%	110.2%	-11.2%	59.8%
Other Principal Arterial	8.7%	-39.9%	-9.2%	-40.7%	-11.2%	-20.8%
Minor Arterial	58.0%	1.5%	42.3%	9.4%	-11.2%	26.8%
Collector	9.2%	-49.0%	-9.2%	-10.9%	-11.2%	-9.9%
Subtotal	**20.1%**	**-23.3%**	**5.1%**	**40.6%**	**-11.2%**	**14.9%**
Total, Federal-Aid Highways*	**-15.2%**	**-19.3%**	**-16.3%**	**-1.1%**	**-11.2%**	**-11.2%**

** The term "Federal-Aid Highways" refers to those portions of the road network that are generally eligible for Federal funding. Roads functionally classified as rural minor collectors, rural local, and urban local are excluded, although some types of Federal program funds can be used on such facilities.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

certain directions in which spending patterns would need to change for scenario goals to be realized. The scenarios can feature shifts in spending across highway functional classes and in highway spending between rehabilitation and expansion because the modeling frameworks determine allocations through benefit-cost optimization. Salient patterns common to all the scenarios and illustrations from particular scenarios include:

- Rural spending decreases relative to 2010. In the **Sustain 2010 Spending** scenario**, total spending remains at the 2010 level, but** spending on rural highways averages 45.8 percent less than the 2010

Exhibit 8-11 Intermediate Improvement Scenario for Federal-Aid Highways: Distribution of Average Annual Investment for 2011 Through 2030, Compared With Actual 2010 Spending, by Functional Class and Improvement Type

Average Annual National Investment on Federal-Aid Highways (Billions of 2010 Dollars)						
	System Rehabilitation			System	System	
Functional Class	Highway	Bridge	Total	Expansion	Enhancement	Total
Rural Arterials and Major Collectors						
Interstate	$1.7	$0.8	$2.5	$1.2	$0.5	$4.3
Other Principal Arterial	$2.3	$0.8	$3.1	$0.7	$0.8	$4.6
Minor Arterial	$2.3	$0.7	$3.0	$0.4	$0.7	$4.1
Major Collector	$3.6	$1.1	$4.7	$0.4	$0.5	$5.6
Subtotal	**$9.9**	**$3.4**	**$13.3**	**$2.7**	**$2.5**	**$18.6**
Urban Arterials and Collectors						
Interstate	$6.0	$2.9	$8.9	$13.2	$1.1	$23.2
Other Freeway and Expressway	$3.1	$1.2	$4.2	$6.1	$0.8	$11.1
Other Principal Arterial	$6.8	$2.1	$8.9	$4.6	$1.8	$15.2
Minor Arterial	$6.5	$1.8	$8.3	$3.7	$1.1	$13.1
Collector	$3.2	$0.7	$3.9	$1.8	$0.6	$6.4
Subtotal	**$25.7**	**$8.6**	**$34.2**	**$29.4**	**$5.4**	**$69.0**
Total, Federal-Aid Highways*	**$35.6**	**$12.0**	**$47.5**	**$32.2**	**$7.9**	**$87.6**

Percent Above Actual 2010 Capital Spending on Federal-Aid Highways by All Levels of Government Combined						
	System Rehabilitation			System	System	
Functional Class	Highway	Bridge	Total	Expansion	Enhancement	Total
Rural Arterials and Major Collectors						
Interstate	-62.7%	22.1%	-51.5%	-8.1%	15.6%	-38.9%
Other Principal Arterial	-47.3%	-14.9%	-41.8%	-82.8%	15.6%	-55.3%
Minor Arterial	-39.7%	-8.2%	-34.5%	-78.2%	15.6%	-40.8%
Major Collector	17.7%	12.3%	16.4%	-65.5%	15.6%	0.0%
Subtotal	**-37.2%**	**2.2%**	**-30.4%**	**-67.7%**	**15.6%**	**-37.7%**
Urban Arterials and Collectors						
Interstate	23.4%	-16.0%	7.1%	233.2%	15.6%	75.7%
Other Freeway and Expressway	56.0%	90.4%	64.2%	196.8%	15.6%	109.1%
Other Principal Arterial	43.6%	-25.0%	18.3%	-11.0%	15.6%	7.4%
Minor Arterial	84.5%	30.9%	69.6%	61.8%	15.6%	61.1%
Collector	45.8%	-35.7%	19.9%	34.5%	15.6%	23.3%
Subtotal	**48.0%**	**-6.9%**	**29.0%**	**98.6%**	**15.6%**	**50.1%**
Total, Federal-Aid Highways*	**7.4%**	**-4.5%**	**4.1%**	**38.1%**	**15.6%**	**15.6%**

** The term "Federal-Aid Highways" refers to those portions of the road network that are generally eligible for Federal funding. Roads functionally classified as rural minor collectors, rural local, and urban local are excluded, although some types of Federal program funds can be used on such facilities.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

level, whereas spending on urban highways averages 29.6 percent more (*Exhibit 8-9*). The rural share of spending in this scenario would be 21.3 percent ($16.1 billion out of $75.8 billion), compared to 39.3 percent in 2010. Even in the **Improve Conditions and Performance** scenario, which funds all projects that appear to be cost-beneficial without consideration of funding constraints, spending on rural highways averages 21.0 percent less than in 2010 (*Exhibit 8-12*).

Exhibit 8-12 Improve Conditions and Performance Scenario for Federal-Aid Highways: Distribution of Average Annual Investment for 2011 Through 2030 Compared With Actual 2010 Spending, by Functional Class and Improvement Type

Average Annual National Investment on Federal-Aid Highways (Billions of 2008 Dollars)						
	System Rehabilitation			System	System	
Functional Class	Highway	Bridge	Total	Expansion	Enhancement	Total
Rural Arterials and Major Collectors						
Interstate	$1.9	$1.1	$2.9	$1.4	$0.7	$5.0
Other Principal Arterial	$2.9	$0.8	$3.7	$1.0	$1.0	$5.7
Minor Arterial	$3.2	$0.8	$4.0	$0.4	$0.9	$5.3
Major Collector	$5.1	$1.2	$6.3	$0.5	$0.7	$7.5
Subtotal	**$13.1**	**$3.9**	**$17.0**	**$3.3**	**$3.2**	**$23.5**
Urban Arterials and Collectors						
Interstate	$6.6	$3.7	$10.3	$16.3	$1.4	$28.0
Other Freeway and Expressway	$3.7	$1.5	$5.2	$8.0	$1.0	$14.2
Other Principal Arterial	$8.7	$3.2	$11.9	$7.4	$2.3	$21.6
Minor Arterial	$7.6	$3.1	$10.8	$5.4	$1.4	$17.6
Collector	$4.1	$1.2	$5.3	$2.7	$0.8	$8.8
Subtotal	**$30.8**	**$12.7**	**$43.5**	**$39.7**	**$7.0**	**$90.2**
Total, Federal-Aid Highways*	**$43.9**	**$16.6**	**$60.4**	**$43.0**	**$10.2**	**$113.7**

Percent Above Actual 2010 Capital Spending on Federal-Aid Highways by All Levels of Government Combined						
	System Rehabilitation			System	System	
Functional Class	Highway	Bridge	Total	Expansion	Enhancement	Total
Rural Arterials and Major Collectors						
Interstate	-58.3%	55.4%	-43.4%	3.1%	50.1%	-28.5%
Other Principal Arterial	-33.1%	-11.4%	-29.4%	-77.4%	50.1%	-44.5%
Minor Arterial	-17.6%	2.8%	-14.2%	-73.9%	50.1%	-23.2%
Major Collector	66.6%	24.8%	56.5%	-54.2%	50.1%	33.9%
Subtotal	**-17.1%**	**16.2%**	**-11.3%**	**-60.9%**	**50.1%**	**-21.0%**
Urban Arterials and Collectors						
Interstate	36.3%	6.8%	24.1%	309.0%	50.1%	111.6%
Other Freeway and Expressway	85.2%	148.9%	100.2%	289.9%	50.1%	166.9%
Other Principal Arterial	84.1%	17.6%	59.6%	44.0%	50.1%	52.9%
Minor Arterial	115.6%	129.7%	119.5%	135.9%	50.1%	116.1%
Collector	86.1%	13.6%	63.1%	95.0%	50.1%	70.1%
Subtotal	**77.5%**	**38.4%**	**64.0%**	**167.9%**	**50.1%**	**96.1%**
Total, Federal-Aid Highways*	**32.4%**	**32.5%**	**32.4%**	**84.7%**	**50.1%**	**50.1%**

** The term "Federal-Aid Highways" refers to those portions of the road network that are generally eligible for Federal funding. Roads functionally classified as rural minor collectors, rural local, and urban local are excluded, although some types of Federal program funds can be used on such facilities.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

- Urban spending increases relative to 2010. Even in the **Maintain Conditions and Performance** scenario, where average annual spending is 11.2 percent lower than base-year 2010 spending overall, total spending on urban highways is 14.9 percent higher (*Exhibit 8-10*).
- For rural highways, the system rehabilitation share of spending increases relative to 2010. In the **Intermediate Improvement** scenario, relative to base-year levels, spending on rural rehabilitation decreases 30.4 percent, but spending on rural expansion decreases proportionally more than twice as much, by 67.7 percent (*Exhibit 8-11*). As a result, the rehabilitation share of rural spending increases from 64.3 percent in the base year to 71.8 percent in the scenario.
- For urban highways, the system expansion share of spending increases on urban highways relative to 2010. In the **Improve Conditions and Performance** scenario, spending on urban system expansion increases 64.0 percent relative to base-year levels, but urban expansion spending increases more than twice as much, by 167.9 percent (*Exhibit 8-12*). As a result, system expansion's share of urban spending increases from 32.2 percent in 2010 to 44.0 percent under this scenario.

The exhibits also display some striking patterns for individual highway functional classes. For example, the scenarios significantly increase the share of rural highway rehabilitation spending that is allocated to rural major collectors. In the **Improve Conditions and Performance** scenario, for instance, relative to levels in 2010, spending on rural highway rehabilitation averages 17.1 percent lower, while the portion of this spending allocated to rural major collectors averages 66.1 percent higher (*Exhibit 8-12*). This and other eye-catching results for individual functional classes reflect features of the models and databases used to simulate the scenarios, as well as investment patterns in 2010 that may or may not continue in the future. In the case of rural major collectors, the increase in this class' share of rehabilitation spending on rural highways stems partly from pavements being rougher on this class than on other rural highway classes, as discussed in Chapter 3.

Suggestive though these patterns are from a policy perspective, some caveats apply. Importantly, differences between spending shares in the scenario for 2011 through 2030 and corresponding spending shares in 2010 do not necessarily indicate misallocations of actual capital spending. Apart from the errors that may result from limitations of the HERS and NBIAS models and the associated databases, two other considerations argue for caution. First, the actual distribution of expenditures among improvement types and functional classes varies from year to year, and 2010 may be atypical in some respects. Second, even if annual highway and bridge investment were to continue on average at the 2010 level, changing circumstances would alter the economically optimal distribution of this spending. The actual distribution in 2010 could, therefore, make perfect economic sense and still differ significantly from the economically optimal distribution over the following 20 years.

Moreover, these results pertain only to Federal-aid highways. The rural shares of spending are relatively modest partly because rural minor collectors (along with rural local and urban local roads) are not classified as such. As discussed in Chapter 2, while Federal-aid highways carry over five-sixths of total VMT, they account for less than one-quarter of total mileage. The system rehabilitation needs on the remaining three-quarters of total mileage are significant.

Scenarios for the National Highway System and the Interstate Highway System

Since the effects of differences in VMT growth have already been revealed in the scenarios for Federal-aid highways, only the forecast rate of growth is considered in the scenarios for the NHS (*Exhibit 8-13*) and the Interstate Highway System (*Exhibit 8-14*). All these scenarios are derived in the same way, and the only non-modeled spending component is system enhancements, which, in 2010, accounted for slightly smaller shares of spending on the NHS and Interstate Highway Systems than on all Federal-aid highways.

Exhibit 8-13 **NHS Capital Investment Scenarios for 2011 through 2030: Derivation, Distribution, and Projected Impacts**

	Sustain 2010 Spending Scenario	Maintain Conditions & Performance Scenario	Intermediate Improvement Scenario	Improve Conditions & Performance Scenario
Scenario Derivation, by Input Components[1, 2]				
Average Annual Investment (Billions of 2010 Dollars)	**$53.9**	**$37.8**	**$58.8**	**$74.9**
HERS-Derived Component (Billions of 2010 Dollars)	$40.6	$27.9	$45.9	$58.1
Percent of Scenario Derived from HERS	75.3%	73.7%	78.1%	77.5%
Annual Percent Change in HERS Spending	0.0%	-3.7%	1.2%	3.3%
Minimum BCR for HERS-Derived Component	1.78	2.73	1.50	1.00
NBIAS-Derived Component (Billions of 2010 Dollars)	$8.7	$6.7	$7.9	$10.5
Percent of Scenario Derived from NBIAS	16.2%	17.8%	13.4%	14.0%
Annual Percent in NBIAS Spending	0.0%	-2.5%	-1.0%	1.7%
Other Component (Billions of 2010 Dollars)	$4.6	$3.2	$5.0	$6.4
Percent of Scenario Derived from Other	8.5%	8.5%	8.5%	8.5%
Distribution by Capital Improvement Type, Average Annual (Billions of 2010 Dollars)[2]				
System Rehabilitation-Highway	$18.1	$13.2	$20.0	$24.0
System Rehabilitation-Bridge	$8.7	$6.7	$7.9	$10.5
System Rehabilitation-Total	$26.9	$20.0	$27.9	$34.5
System Expansion	$22.4	$14.6	$25.9	$34.1
System Enhancement	$4.6	$3.2	$5.0	$6.4
Total, All Improvement Types	**$53.9**	**$37.8**	**$58.8**	**$74.9**
Percent Distribution by Capital Improvement Type[2]				
System Rehabilitation	49.9%	52.8%	47.4%	46.0%
System Expansion	41.6%	38.7%	44.1%	45.5%
System Enhancement	8.5%	8.5%	8.5%	8.5%
Projected 2030 Values for Selected Indicators[2]				
Average Bridge Sufficiency Rating	84.1	82.5	83.6	84.7
Percent of VMT on Roads with Good Ride Quality	80.2%	67.7%	83.5%	89.6%
Percent of VMT on Roads with Acceptable Ride Quality	93.9%	90.5%	94.9%	96.7%
Projected Changes by 2030 Relative to 2010 for Selected Indicators[2]				
Percent Change in Average IRI[3]	-23.7%	-8.4%	-27.7%	-35.3%
Percent Change in Average Delay	-5.9%	6.7%	-10.2%	-18.3%

[1] *Each scenario consists of three separately estimated components. The HERS-derived scenario components are linked directly to the analyses presented in* Exhibits 7-12 *through* 7-13 *in Chapter 7 that assumed future VMT consistent with HPMS forecasts; the NBIAS-derived components are linked directly to the analysis presented in* Exhibit 7-18. *These components can be cross-referenced to those exhibits using the annual percent change in HERS spending or NBIAS spending reflected in this table. The third scenario component, identified as "Other," represents types of capital spending beyond those modeled in HERS or NBIAS; each scenario assumes that the percentage of total spending on these items in the future will remain the same as in 2010.*

[2] *The NHS statistics presented in this chapter are intended to approximate the NHS as it will exist after its expansion directed by MAP-21, not the NHS as it existed in 2010.*

[3] *Reductions in average pavement roughness (IRI) translate into improved ride quality.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

Exhibit 8-14 **Interstate System Capital Investment Scenarios for 2011 through 2030: Derivation, Distribution, and Projected Impacts**

	Sustain 2010 Spending Scenario	Maintain Conditions & Performance Scenario	Intermediate Improvement Scenario	Improve Conditions & Performance Scenario
Scenario Derivation, by Input Components[1]				
Average Annual Investment (Billions of 2010 Dollars)	**$20.2**	**$17.4**	**$27.8**	**$33.1**
HERS-Derived Component (Billions of 2010 Dollars)	$14.7	$12.9	$22.2	$26.2
Percent of Scenario Derived from HERS	72.7%	74.1%	79.6%	78.9%
Annual Percent Change in HERS Spending	0.0%	-1.3%	3.8%	5.2%
Minimum BCR for HERS-Derived Component	2.72	2.84	1.50	1.00
NBIAS-Derived Component (Billions of 2010 Dollars)	$4.1	$3.3	$3.7	$4.7
Percent of Scenario Derived from NBIAS	20.4%	18.9%	13.4%	14.1%
Annual Percent in NBIAS Spending	0.0%	-2.2%	-0.9%	1.2%
Other Component (Billions of 2010 Dollars)	$1.4	$1.2	$1.9	$2.3
Percent of Scenario Derived from Other	6.9%	6.9%	6.9%	6.9%
Distribution by Capital Improvement Type, Average Annual (Billions of 2010 Dollars)				
System Rehabilitation-Highway	$5.8	$5.3	$7.7	$8.5
System Rehabilitation-Bridge	$4.1	$3.3	$3.7	$4.7
System Rehabilitation-Total	$9.9	$8.6	$11.4	$13.2
System Expansion	$8.9	$7.6	$14.5	$17.6
System Enhancement	$1.4	$1.2	$1.9	$2.3
Total, All Improvement Types	**$20.2**	**$17.4**	**$27.8**	**$33.1**
Percent Distribution by Capital Improvement Type				
System Rehabilitation	49.0%	49.3%	41.0%	39.8%
System Expansion	44.1%	43.8%	52.0%	53.3%
System Enhancement	6.9%	6.9%	6.9%	6.9%
Projected 2030 Values for Selected Indicators				
Average Bridge Sufficiency Rating	84.0	82.3	83.4	84.5
Percent of VMT on Roads with Good Ride Quality	80.3%	76.8%	90.8%	94.2%
Percent of VMT on Roads with Acceptable Ride Quality	96.2%	95.4%	98.9%	99.6%
Projected Changes by 2030 Relative to 2010 for Selected Indicators				
Percent Change in Average IRI[2]	-12.7%	-6.5%	-28.2%	-32.9%
Percent Change in Average Delay	1.0%	10.1%	-27.3%	-39.5%

[1] *Each scenario consists of three separately estimated components. The HERS-derived scenario components are linked directly to the analyses presented in* Exhibits 7-14 *through* 7-15 *in Chapter 7 that assumed future VMT consistent with HPMS forecasts; the NBIAS-derived components are linked directly to the analysis presented in* Exhibit 7-19. *These components can be cross-referenced to those exhibits using the annual percent change in HERS spending or NBIAS spending reflected in this table. The third scenario component, identified as "Other," represents types of capital spending beyond those modeled in HERS or NBIAS; each scenario assumes that the percentage of total spending on these items in the future will remain the same as in 2010.*

[2] *Reductions in average pavement roughness (IRI) translate into improved ride quality.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

Comparison of these scenarios with the Federal-aid highway scenarios reveals several patterns of interest:

- The shares of spending directed to system rehabilitation are smaller, particularly in the Interstate Highway System scenarios, than in the Federal-aid highway scenarios. In the **Improve Conditions and Performance** scenario, the rehabilitation share is 53.2 percent when the scenario relates to Federal-aid highways (*Exhibit 8-7*) and 39.8 percent when it relates to Interstate highways (*Exhibit 8-14*).
- In the **Maintain Conditions and Performance** scenario**,** future annual spending on Interstate highways averages $17.4 billion when the scenario concerns only those highways versus $22.0 billion ($3.8 billion plus $18.2 billion from *Exhibit 8-10*) when it considers all Federal-aid highways. In combination, HERS and NBIAS found that the most cost-effective way to maintain overall system conditions and performance would be, on average, to improve them somewhat on the Interstate System, and to let them deteriorate somewhat on non-Interstate routes. Similarly, in the **Sustain 2010 Spending** scenario, future annual spending on Interstate highways averages $20.2 billion versus $24.4 billion ($4.1 billion plus $20.3 billion from *Exhibit 8-9*) when it considers all Federal-aid highways. This again suggests that an economically driven approach to investment in highways and bridges would favor the Interstate highways.
- Projected changes between 2010 and 2030 in average pavement roughness and average delay are more favorable in these scenarios than in those for Federal-aid highways. In the **Improve Conditions and Performance** scenario, when the scenario concerns only Interstate highways, the average IRI is projected to decrease by 32.9 percent and average delay by 39.5 percent; when the focus extends to all Federal-aid highways, the reductions are 26.7 percent and 8.0 percent (*Exhibit 8-7*). By design, no matter which set of roads is the focus, the **Maintain Conditions and Performance** scenario projections indicate no unambiguous improvement or deterioration in conditions and performance. The projected outcomes for the bridge condition indices also appear relatively invariant to changes in focus among Federal-aid highways, the NHS, and Interstate highways.

Highway and Bridge Investment Backlog

The investment backlog represents all highway and bridge improvements that could be economically justified for immediate implementation, based solely on the current conditions and operational performance of the highway system (without regard to potential future increases in VMT or potential future physical deterioration of infrastructure assets). Conceptually, the backlog represents a subset of the investment levels reflected in the **Improve Conditions and Performance** scenario, which addresses the existing backlog as well as additional projected pavement, bridge, and capacity needs that may arise over the next 20 years.

Exhibit 8-15 presents an estimate of the backlog in 2010 for the types of capital improvements that are modeled in HERS and NBIAS, plus an adjustment factor for nonmodeled capital improvement types. The portion of the backlog derived from NBIAS amounts to $106.4 billion in spending on bridge rehabilitation. The portion derived from HERS, $598.6 billion, is much larger and represents the pool of cost-beneficial investments in system expansion and pavement improvements based solely on conditions and performance in 2010.

Of the estimated $808.2 total backlog, approximately $189.4 billion (23.4 percent) is on the Interstate Highway System and $441.4 billion (54.6 percent) is on the NHS (which includes the Interstate Highway System). Approximately 59.3 percent ($479.1 billion) of the total backlog is attributable to system rehabilitation needs, while the remainder is mainly associated with system expansion improvements to address existing capacity deficiencies. The share of the total backlog attributable to system rehabilitation is progressively lower for Federal-aid highways (60.6 percent), the NHS (56.8 percent), and the Interstate Highway System (47.4 percent).

Exhibit 8-15 **Estimated Highway and Bridge Investment Backlog as of 2010**

System Component	(Billions of 2010 Dollars) System Rehabilitation Highway	Bridge	Total	System Expansion	System Enhancement*	Total	Percent of Total
Federal-Aid Highways—Rural	$57.3	$28.4	$85.7	$8.8	*$17.4*	$111.9	13.9%
Federal-Aid Highways—Urban	$236.5	$58.5	$294.9	$184.0	*$37.6*	$516.5	63.9%
Federal-Aid Highways—Total	$293.8	$86.8	$380.6	$192.9	*$55.0*	$628.5	77.8%
Non-Federal-Aid Highways*	*$78.9*	$19.6	$98.5	*$33.1*	*$48.2*	$179.8	22.2%
All Roads*	**$372.7**	**$106.4**	**$479.1**	**$225.9**	**$103.1**	**$808.2**	**100.0%**
Interstate Highway System	$59.4	$30.4	$89.8	$86.4	*$13.1*	$189.4	23.4%
National Highway System	$191.3	$59.2	$250.6	$153.4	*$37.4*	$441.4	54.6%

* *Italicized values are estimates for those system components and capital improvement types not modeled in HERS or NBIAS, such as system enhancements, as well as pavement and expansion improvements to roads functionally classified as rural minor collector, rural local, or urban local, for which HPMS data are not available to support an HERS analysis.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

The $808.2 billion estimated backlog is heavily weighted toward urban areas; approximately 63.9 percent of this total is attributable to Federal-aid highways in urban areas. As noted in Chapter 3, average pavement ride quality on Federal-aid highways in 2008 was worse in urban areas than rural areas; urban areas also face relatively greater problems with congestion and functionally obsolete bridges than do rural areas.

It should be noted that the $808.2-billion backlog is considerably higher than that presented in previous C&P reports because it includes $215.1 billion for the types of capital improvements that are not modeled in HERS or NBIAS; nonmodeled investment types were previously excluded.

Selected Transit Capital Investment Scenarios

While Chapter 7 considered the impacts of varying levels of capital investment on transit conditions and performance, this chapter provides in-depth analysis of four specific investment scenarios, as outlined below in *Exhibit 8-16*. The Sustain 2010 Spending scenario assesses the impact of sustaining current expenditure levels on asset conditions and system performance over the next 20-year period. Given that current expenditure rates are generally less than are required to maintain current condition and performance levels, this scenario reflects the magnitude of the expected declines in conditions and performance given maintenance of current capital investment rates. The state of good repair (SGR) benchmark considers the level of investment required to eliminate the existing capital investment backlog as well as the condition and performance impacts of doing so. In contrast to the other scenarios considered here, the SGR benchmark only considers the preservation needs of existing transit assets (with no consideration of expansion requirements). Moreover, this is the only scenario that does not require that investments pass the Transit Economic Requirements Model's (TERM's) benefit-cost test (hence, this scenario brings all assets to an SGR regardless of TERM's assessment of whether reinvestment is warranted). Finally, the Low Growth and High Growth scenarios both assess the required levels of reinvestment to (1) preserve existing transit assets at a condition rating of 2.5 or higher and (2) expand transit service capacity to support differing levels of ridership growth while passing TERM's benefit-cost test.

Exhibit 8-16 **2010 C&P Analysis Scenarios for Transit**

Scenario Aspect	Sustain 2010 Spending	SGR	Low Growth (MPO Projected Growth)	High Growth (Historical Growth)
Description	Sustain preservation and expansion spending at current levels over next 20 years	Level of investment to attain and maintain SGR over next 20 years (no assessment of expansion needs)	Preserve existing assets and expand asset base to support MPO projected ridership growth (about 1.4%)	Preserve existing assets and expand asset base to support historical rate of ridership growth (2.2% between 1995 and 2010)
Objective	Assess impact of constrained funding on condition, SGR backlog, and ridership capacity	Requirements to attain SGR (as defined by assets in condition 2.5 or better)	Assess unconstrained preservation and capacity expansion needs assuming low ridership growth	Assess unconstrained preservation and capacity expansion needs assuming high ridership growth
Apply Benefit-Cost Test?	Yes[1]	No	Yes	Yes
Preservation?	Yes[2]	Yes[2]	Yes[2]	Yes[2]
Expansion?	Yes	No	Yes	Yes

[1] To prioritize investments under constrained funding.

[2] Replace at condition 2.5.

Exhibit 8-17 summarizes the analysis results for each of these scenarios. It should be noted that each of the scenarios presented in *Exhibit 8-17* imposes the same asset condition replacement threshold (i.e., assets are replaced at condition rating 2.5 when there is sufficient budget to do so) when assessing transit reinvestment needs. Hence, the differences in the total preservation expenditure amounts across each of these scenarios primarily reflect the impact of either (1) an imposed budget constraint (Sustain 2010 Spending scenario)

or (2) application of TERM's benefit-cost test (the SGR benchmark does not apply the benefit-cost test). A brief review of *Exhibit 8-17* reveals the following:

- Sustain 2010 Spending Scenario: Total spending under this scenario is well below that of each of the other needs-based scenarios, indicating that sustaining recent spending levels is insufficient to attain the investment objectives of the SGR, Low Growth, or High Growth scenarios (suggesting future increases in the size of the SGR backlog and a likely increase in the number of transit riders per peak vehicle—including an increased incidence of crowding—in the absence of increased expenditures).
- SGR Benchmark: The level of expenditures required to attain and maintain an SGR over the upcoming 20-year period—which covers preservation needs but excludes any expenditures on expansion investments—is 12 percent higher than that currently expended on asset preservation and expansion combined.
- Low and High Growth Scenarios: The level of investment to address expected preservation and expansion needs is estimated to be roughly 33 percent to 49 percent higher than currently expended by the Nation's transit operators. Preservation and expansion needs are highest for urbanized areas (UZAs) exceeding 1 million in population.

The following subsections present more detailed assessments of each scenario.

Exhibit 8-17 Annual Average Cost by Investment Scenario (2010–2030)

Mode, Purpose, and Asset Type	Investment Projection (Billions of 2010 Dollars) Sustain 2010 Spending	SGR	Low Growth	High Growth
Urbanized Areas Over 1 Million in Population[1]				
Nonrail[2]				
Preservation	$2.9	$4.6	$4.2	$4.2
Expansion	$1.2	$0.0	$1.2	$2.1
Subtotal Nonrail[3]	**$4.1**	**$4.6**	**$5.4**	**$6.3**
Rail				
Preservation	$6.3	$11.4	$11.0	$11.1
Expansion	$4.2	$0.0	$2.9	$4.0
Subtotal Rail[3]	**$10.5**	**$11.4**	**$13.9**	**$15.1**
Total, Over 1 Million in Population[3]	**$14.6**	**$16.0**	**$19.3**	**$21.4**
Urbanized Areas Under 1 Million in Population and Rural				
Nonrail[2]				
Preservation	$1.1	$2.2	$1.9	$1.9
Expansion	$0.6	$0.0	$0.5	$1.0
Subtotal Nonrail[3]	**$1.7**	**$2.2**	**$2.4**	**$2.9**
Rail				
Preservation	$0.0	$0.3	$0.2	$0.2
Expansion	$0.2	$0.0	$0.0	$0.0
Subtotal Rail[3]	**$0.2**	**$0.3**	**$0.2**	**$0.2**
Total, Under 1 Million and Rural[3]	**$1.9**	**$2.5**	**$2.7**	**$3.1**
Total[3]	**$16.5**	**$18.5**	**$22.0**	**$24.5**

[1] Includes 37 different urbanized areas.

[2] Buses, vans, and other (including ferryboats).

[3] Note that totals may not sum due to rounding.

Source: Transit Economic Requirements Model.

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Sustain 2010 Spending Scenario

In 2010, as reported by transit agencies to the National Transit Database (NTD), transit operators spent a total of $16.5 billion on capital projects (see *Exhibit 7-20* and the corresponding discussion in Chapter 7). Of this amount, $10.3 billion was dedicated to the preservation of existing assets while the remaining $6.2 billion was dedicated to investment in asset expansion, both to support ongoing ridership growth and to improve service performance. This Sustain 2010 Spending scenario considers the expected impact on the long-term physical conditions and service performance of the Nation's transit infrastructure if these 2010 expenditure levels are sustained in constant dollar terms through 2030. Similar to the discussion in Chapter 7, the analysis considers the impacts of asset preservation investments separately from those of asset expansion.

Capital Expenditures for 2010. As reported to the NTD, the level of transit capital expenditures peaked in 2009 at $16.6 billion and experienced a slight decrease in 2010 to $16.5 billion. (See *Exhibit 8-18.*) Although the annual transit capital expenditures averaged $14.3 billion from 2004 to 2010, expenditures averaged $16.4 billion in the last three years of NTD reporting. Furthermore, even though capital expenditures for preservation purposes in 2010 decreased $1.0 billion relative to prior year levels, capital expenditures for expansion purposes increased $0.9 billion in 2010.

TERM's Funding Allocation. The following analysis of the Sustain 2010 Spending scenario relies on TERM's allocation of 2010-level preservation and expansion expenditures to the Nation's existing transit operators, their modes, and their assets over the upcoming 20-year period as depicted in *Exhibit 8-19*. As with other TERM analyses involving the allocation of constrained transit funds, TERM allocates limited funds based on the results of the model's benefit-cost analysis, which ranks potential investments based on their assessed benefit-cost ratios (with the highest-ranked investments being funded first). Note that this TERM benefit-cost–based allocation of funding between assets and modes may differ from the allocation that local agencies might actually pursue assuming that total spending is sustained at current levels over 20 years.

Exhibit 8-18 Annual Transit Capital Expenditures, 2004 to 2010 (Billions of Current-Year Dollars)

Year	Preservation	Expansion	Total
2004	$9.4	$3.2	$12.6
2005	$9.0	$2.9	$11.8
2006	$9.3	$3.5	$12.8
2007	$9.6	$4.0	$13.6
2008	$11.0	$5.1	$16.1
2009	$11.3	$5.3	$16.6
2010	$10.3	$6.2	$16.5
Average	**$10.0**	**$4.3**	**$14.3**
Expenditures 2004 to 2010 in 2010 Dollars			
Average	**$10.5**	**$4.5**	**$15.0**

Source: National Transit Database.

Exhibit 8-19 Sustain 2010 Spending Scenario: Average Annual Investment by Asset Type, 2010–2030 (Billions of 2010 Dollars)

	Investment Category		
Asset Type	Preservation	Expansion	Total
Rail			
Guideway Elements	$1.2	$1.2	$2.4
Facilities	$0.0	$0.1	$0.1
Systems	$2.3	$0.2	$2.5
Stations	$0.4	$0.6	$1.1
Vehicles	$2.4	$1.1	$3.5
Other Project Costs	$0.0	$1.1	$1.1
Subtotal Rail*	**$6.3**	**$4.4**	**$10.7**
Nonrail			
Guideway Elements	$0.0	$0.1	$0.1
Facilities	$0.1	$0.3	$0.4
Systems	$0.1	$0.1	$0.2
Stations	$0.0	$0.0	$0.1
Vehicles	$3.8	$1.2	$5.0
Other Project Costs	$0.0	$0.0	$0.0
Subtotal Nonrail*	**$4.0**	**$1.8**	**$5.8**
Total*	**$10.3**	**$6.2**	**$16.5**

** Note that totals may not sum due to rounding.*

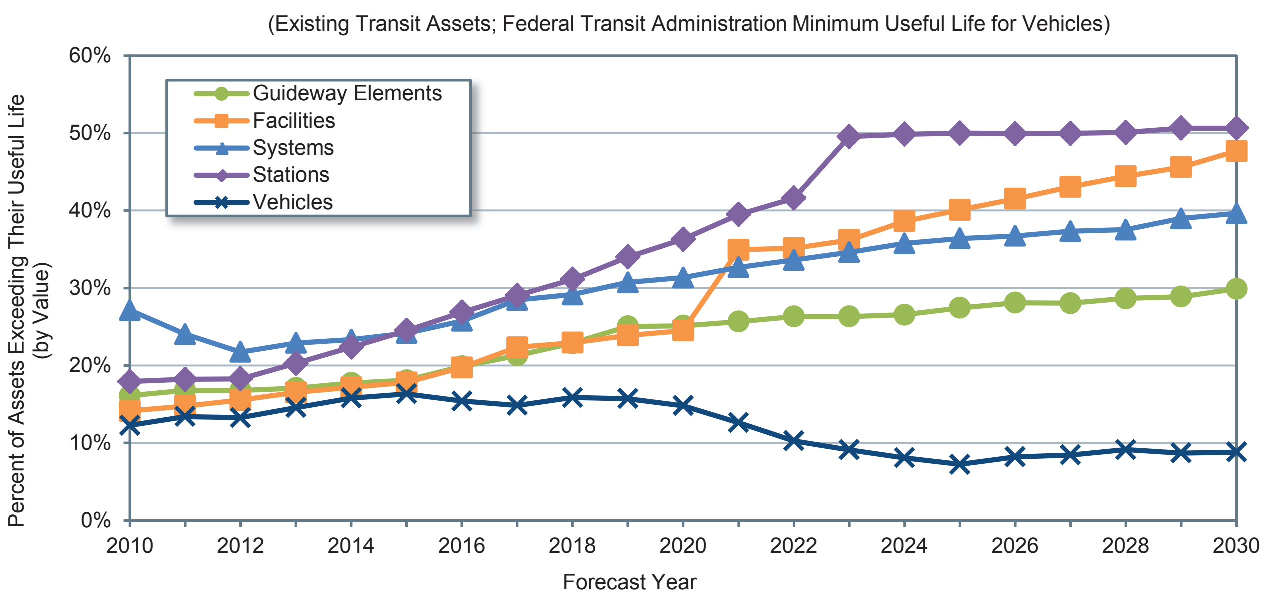
Source: Transit Economic Requirements Model and FTA staff estimates.

Preservation Investments

As noted above, transit operators spent an estimated $10.3 billion in 2010 on the rehabilitation and replacement of existing transit infrastructure. Based on current TERM analyses, this level of reinvestment is less than that required to address the anticipated reinvestment needs of the Nation's existing transit assets, and, if sustained over the forecasted 20-year period, would result in an overall decline in the condition of existing transit assets as well as an increase in the size of the investment backlog.

For example, *Exhibit 8-20* presents the projected increase in the proportion of existing assets that exceed their useful life by asset category during the period from 2010 to 2030. Given the benefit-cost-based prioritization imposed by TERM for this scenario, the proportion of existing assets that exceed their useful life is projected to undergo a near-continuous increase across each of these asset categories. (This condition projection uses TERM's benefit-cost test to prioritize rehabilitation and replacement investments in this scenario. Specifically, for each investment period in the forecast, TERM ranks all proposed investment activities based on their assessed benefit-cost ratios [highest to lowest.) TERM then invests in the highest-ranked projects for each period until the available funding for the period is exhausted. It is apparent here that TERM investment priorities favor vehicle investments (as do those of most transit agencies). Between 2015 and 2025 TERM invests in vehicles, which rate highly on several investment criteria, decreasing the vehicle over-age forecast over this time period. (Investments not addressed in the current period as a result of the funding constraint are then deferred until the following period.) Also, given that the proportion of over-age assets is projected to increase for all asset categories under this prioritization, it is clear that any reprioritization to favor reinvestment in one asset category over another would accelerate the rate of increase of the remaining categories. Note that these over-age assets tend to deliver the lowest-quality transit service to system users (e.g., have the highest likelihood of in-service failures).

Exhibit 8-20 Sustain 2010 Spending Scenario: Over-Age Forecast by Asset Category, 2010–2030

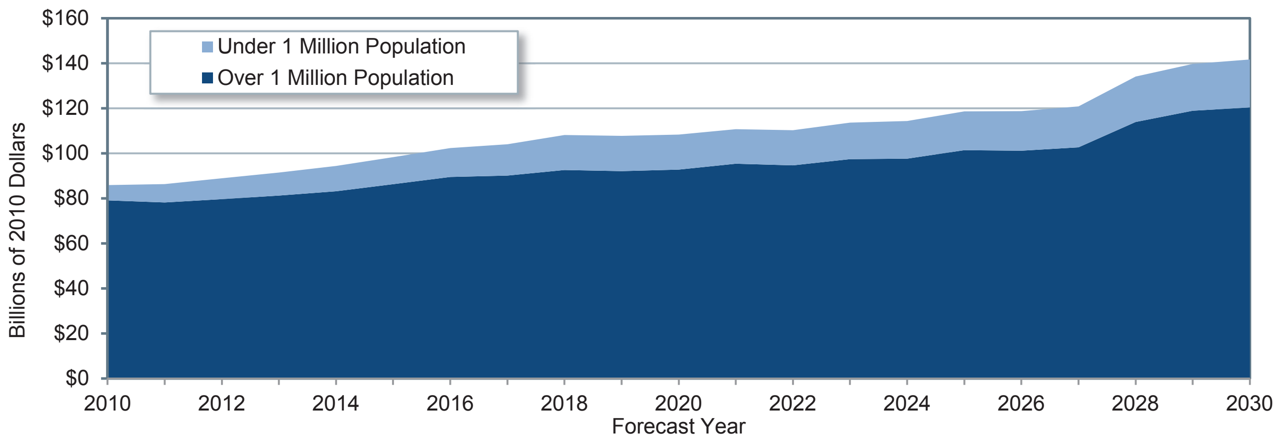


Note: The proportion of assets exceeding their useful life is measured based on asset replacement value, not asset quantities.
Source: Transit Economic Requirements Model.

Finally, *Exhibit 8-21* presents the projected change in the size of the investment backlog if reinvestment levels are sustained at the 2010 level of $10.3 billion, in constant dollar terms. As described in Chapter 7, the investment backlog represents the level of investment required to replace all assets that exceed their useful life and also to address all rehabilitation activities that are currently past due. Given that the current rate of

capital reinvestment is insufficient to address the replacement needs of the existing stock of transit assets, the size of that backlog is projected to increase from the currently estimated level of $85.9 billion to roughly $142.0 billion by 2030. This chart also divides the backlog amount according to transit service area size, with the lower portion showing the backlog for UZAs with populations greater than 1 million and the upper portion showing the backlog for all other UZAs and rural areas combined. This segmentation highlights the significantly higher existing backlog for those UZAs serving the largest number of transit riders. The initial reduction in the backlog for these largest-transit UZAs, as shown in *Exhibit 8-21*, results from TERM's higher prioritization of replacement needs for this urban area type and does not necessarily reflect the actual or expected allocation of expenditures between urban area types given maintenance of current spending levels in the future. Regardless of the actual allocation, it is clear that the 2010 expenditure level of $10.3 billion, if sustained, is not sufficient to prevent a further increase in the backlog needs of one or more of these UZA types.

Exhibit 8-21 Investment Backlog: Sustain 2010 Spending ($10.3 Billion Annually)



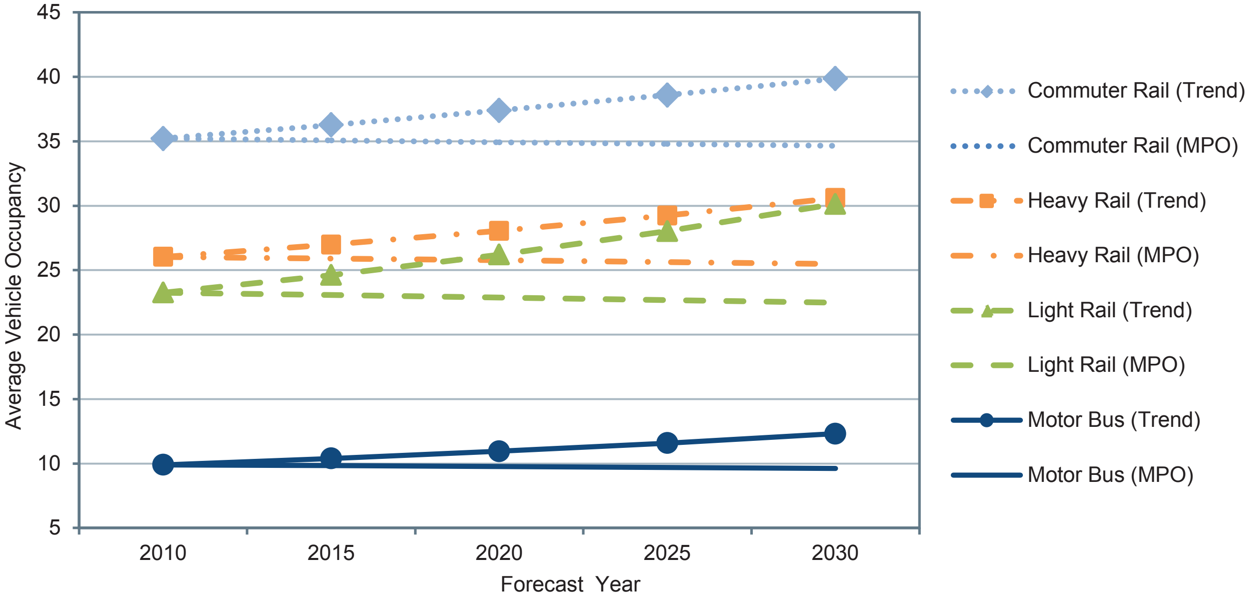
Source: Transit Economic Requirements Model.

Expansion Investments

In addition to the $10.3 billion spent on transit asset preservation in 2010, transit agencies spent $6.2 billion on expansion investments to support ridership growth and to improve transit performance. This section considers the impact of sustaining the 2010 level of expansion investment on future ridership capacity and vehicle utilization rates under both lower and higher ridership growth rate assumptions. As noted above, it is important to consider here that the $6.2 billion spent on expansion investments in 2010 was significantly higher than that reported in prior years.

As already considered in Chapter 7 (see *Exhibit 7-23*), the 2010 rate of investment in transit expansion is not sufficient to expand transit capacity at a rate equal to the rate of growth in travel demand, as projected by the historical trend rate of increase. Under these circumstances, it should be expected that transit capacity utilization (e.g., passengers per vehicle) will increase, with the level of increase determined by actual growth in demand. Although the impact of this change may be minimal for systems that currently have lower capacity utilization, service performance on some higher utilization systems would likely decline as riders experience increased vehicle crowding and potential for service delays. This impact is illustrated in *Exhibit 8-22*, which presents the projected change in vehicle occupancy rates by mode during the period from 2010 through 2030 (reflecting the impacts of spending from 2009 through 2030) under both lower (metropolitan planning organization [MPO]) and higher (trend) rates of growth scenarios in transit ridership, assuming that transit agencies continue to invest an average of $6.2 billion per year on transit expansion. Under the MPO-projected rate of increase, capacity utilization is stable, indicating that investment is sufficient. However, for the higher historical trend rates of increase, there is a steady rise in the

Exhibit 8-22 **Sustain 2010 Spending Scenario: Capacity Utilization by Mode Forecast, 2010–2030**

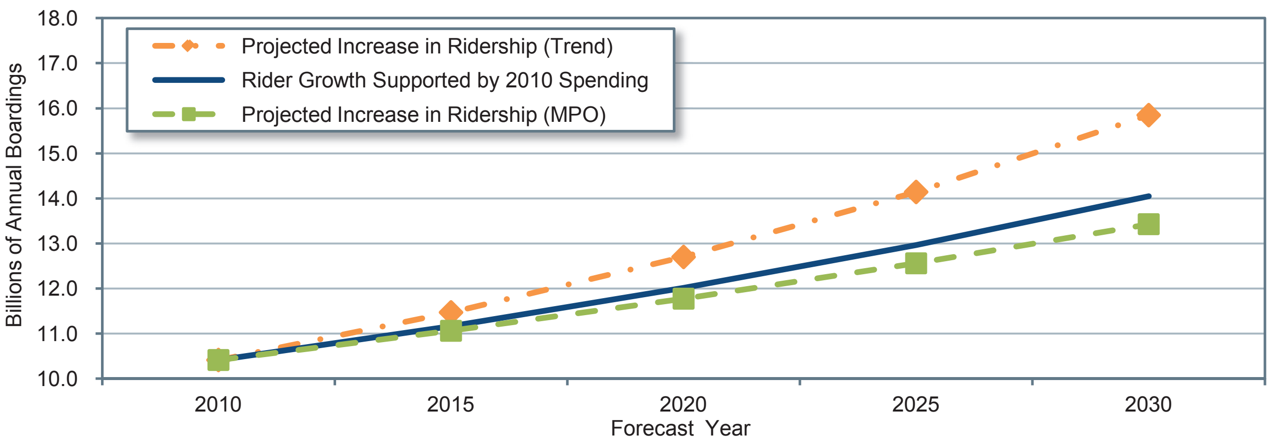


Source: Transit Economic Requirements Model.

average number of riders per transit vehicle across each of the four modes depicted here. For perspective, note that MPO growth rate projections tend to be conservative because they are developed based on financially constrained transportation plans. Moreover, the actual growth in travel demand has typically exceeded the MPO growth projections for much of the past decade.

Exhibit 8-23 presents the projected growth in transit riders that can be supported by the 2010 level of investment (keeping vehicle occupancy rates constant) as compared with the potential growth in total ridership under both the lower and higher growth rate scenarios. Similar to prior analyses, the $6.2-billion level of investment for expansion can support ridership growth that is similar to the MPO-projected ridership increases, but is short of that required to support continued ridership growth at recent historical rates (i.e., without impacting service performance).

Exhibit 8-23 **Projected Versus Currently Supported Ridership Growth**



Source: Transit Economic Requirements Model.

State of Good Repair Benchmark

The preceding scenario considered the impacts of sustaining transit spending at current levels, which appear to be insufficient to address either deferred investment needs (which are projected to increase) or the projected trends in transit ridership (without a reduction in service performance). In contrast, this section focuses on the level of investment required to eliminate the investment backlog over the next 20 years and to provide for sustainable rehabilitation and replacement needs once the backlog has been addressed. Specifically, the SGR benchmark estimates the level of annual investment required to replace assets that currently exceed their useful life, to address all deferred rehabilitation activities (yielding an SGR where the asset has a condition rating of 2.5 or higher), and then to address all future rehabilitation and replacement activities as they come due. The SGR benchmark considered here uses the same methodology as that described in the Federal Transit Administration's National State of Good Repair Assessment, released June 2010.

> **What is the definition of a state of good repair (SGR)?**
>
> Q&A
>
> The definition of "state of good repair" used for this scenario relies on TERM's assessment of transit asset conditions. Specifically, for this scenario, TERM considers assets to be in a state of good repair if they are rated at a condition rating of 2.50 or higher and if all required rehabilitation activities have been addressed.

Differences with Other Scenarios: In contrast to the other scenarios in this chapter, the SGR benchmark (1) makes no assessment of expansion needs and (2) does not apply TERM's benefit-cost test to investments proposed by TERM. These benchmark characteristics are inconsistent with the SGR concept. First, analyses of expansion investments are ultimately focused on capacity improvements and not on the needs of deteriorated assets. Second, application of TERM's benefit-cost test would leave some reinvestment needs unaddressed. The intention of this benchmark is to assess the total magnitude of unaddressed reinvestment needs for all transit assets currently in service, regardless of whether it appears to be cost-beneficial for these assets to remain in service.

SGR Investment Needs

Annual reinvestment needs under the SGR benchmark are presented in *Exhibit 8-24*. Under this benchmark, an estimated $ 18.5 billion in annual expenditures will be required over the next 20 years to bring the condition of all existing transit assets to an SGR. Of this amount, roughly $11.7 billion (63 percent) is required to address the SGR needs of rail assets. Note that a large proportion of rail reinvestment needs are associated with guideway elements (primarily aging elevated and tunnel structures) and rail systems (including train control, traction power, and communications systems) that are past their useful life as well as potentially technologically obsolete. Bus-related reinvestment needs are primarily associated with aging vehicle fleets.

Exhibit 8-24 also provides a breakout of capital reinvestment needs by type of UZA. This breakout emphasizes the fact that capital reinvestment needs are most heavily concentrated in the Nation's larger UZAs. Together, these urban areas account

Exhibit 8-24 SGR Benchmark: Average Annual Investment by Asset Type, 2010–2030 (Billions of 2010 Dollars)

	Urban Area Type		
Asset Type	Over 1 Million Population	Under 1 Million Population	Total
Rail			
Guideway Elements	$2.8	$0.1	$2.9
Facilities	$0.8	$0.1	$0.9
Systems	$3.4	$0.0	$3.4
Stations	$2.0	$0.0	$2.0
Vehicles	$2.5	$0.0	$2.5
Subtotal Rail*	**$11.4**	**$0.3**	**$11.7**
Nonrail			
Guideway Elements	$0.4	$0.1	$0.5
Facilities	$0.9	$0.7	$1.6
Systems	$0.2	$0.0	$0.2
Stations	$0.1	$0.0	$0.1
Vehicles	$3.0	$1.3	$4.3
Subtotal Nonrail*	**$4.6**	**$2.2**	**$6.7**
Total*	**$16.0**	**$2.5**	**$18.5**

** Note that totals may not sum due to rounding.*

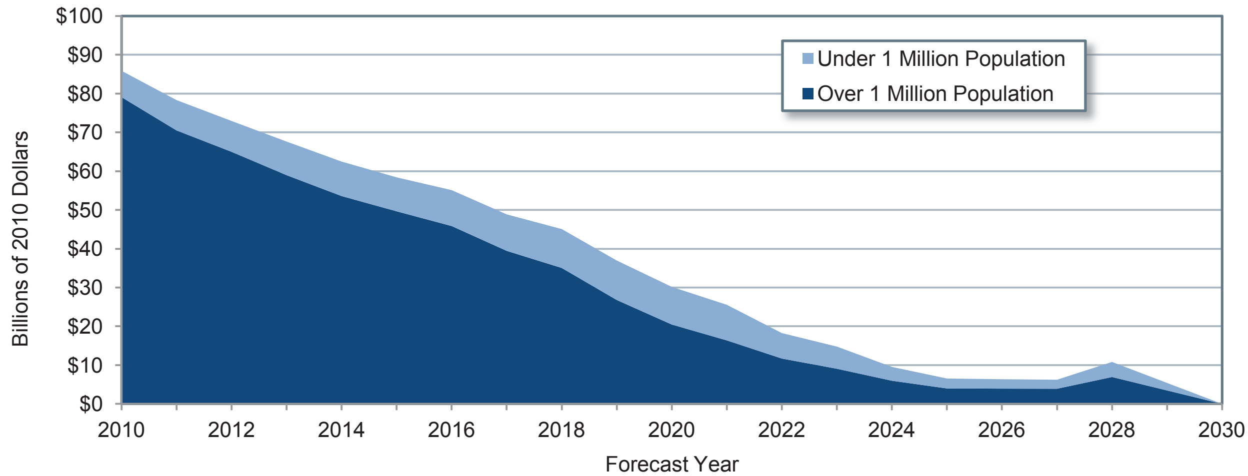
Source: Transit Economic Requirements Model.

for approximately 86 percent of total reinvestment needs (across all mode and asset types), with the rail reinvestment needs of these urban areas accounting for more than one-half of the total reinvestment required to bring all assets to an SGR. This high proportion of total needs reflects the high level of investment in older assets found in these urban areas.

Impact on the Investment Backlog

A key objective of the SGR benchmark is to determine the level of investment required to attain and then maintain an SGR across all transit assets over the next 20 years, including elimination of the existing investment backlog. *Exhibit 8-25* shows the estimated impact of the $18.5 billion in annual expenditures under the SGR benchmark on the existing investment backlog over the 20-year forecast period (compare these data with *Exhibit 8-21*). Given this level of expenditures, the backlog is projected to be eliminated by 2030, with the majority of this drawdown addressing the reinvestment needs of the UZAs with populations greater than 1 million.

Exhibit 8-25 Investment Backlog: State of Good Repair Benchmark ($18.5 Billion Annually)



Source: Transit Economic Requirements Model.

Impact on Conditions

In drawing down the investment backlog, the annual capital expenditures of $18.5 billion under the SGR benchmark would also lead to the replacement of assets with an estimated condition rating of 2.5 or lower. Within TERM's condition rating system, this includes assets in marginal condition that have ratings of below 2.5 and all assets in poor condition. *Exhibit 8-26* shows the current distribution of asset conditions for assets estimated to be in a rating condition of 2.5 or lower (with assets in poor condition segmented into two sub-groups). Note that this graphic excludes both tunnel structures and subway stations in tunnel structures because these are considered assets that require ongoing capital rehabilitation expenditures but that are never actually replaced. As with the investment backlog, the proportion of assets at condition rating 2.5 or lower is projected to decrease under the SGR benchmark from roughly 10 percent of assets in 2010 to well below 1 percent by 2030. Once again, this replacement activity would remove from service those assets with higher occurrences of service failures, technological obsolescence, and lower overall service quality.

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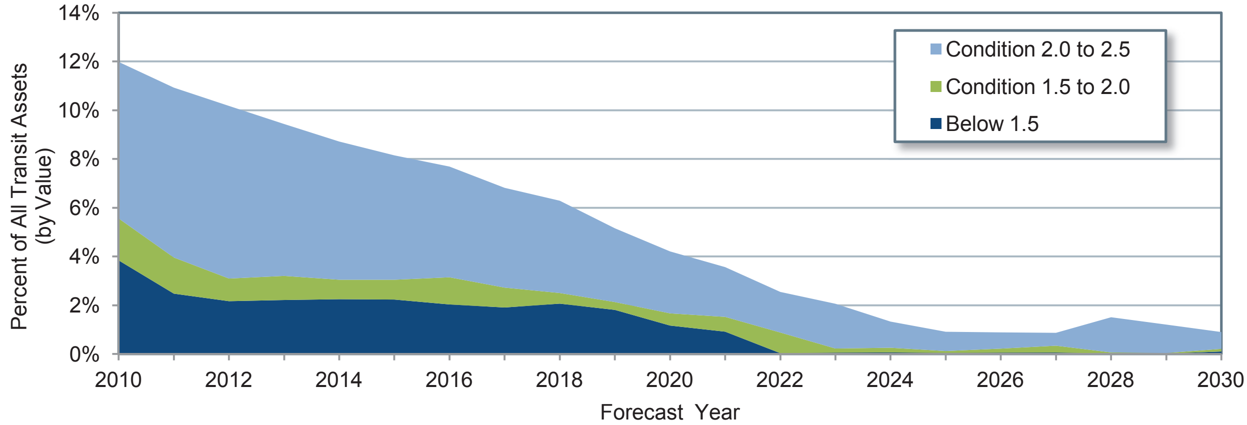
Exhibit 8-26 **Proportion of Transit Assets Not in State of Good Repair (Excluding Tunnel Structures)**

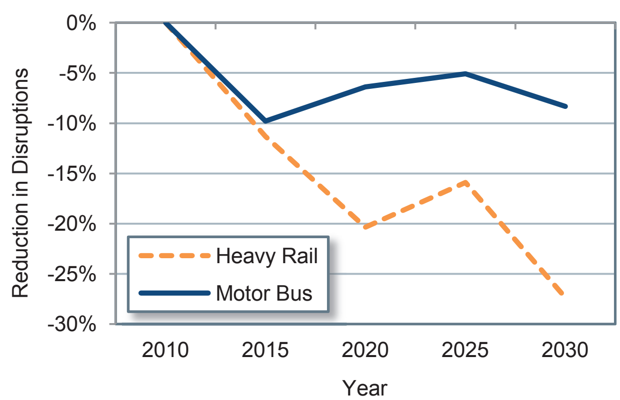


Source: Transit Economic Requirements Model.

Impact on Vehicle Fleet Performance

While the preceding analysis considered the impact of higher investment on reducing the investment backlog and potential replacement of assets past their useful life, this analysis may not provide a sense of the potential positive implications of these changes for daily transit service. To help better understand these effects, *Exhibit 8-27* shows the estimated percent reduction in fleet-wide revenue service disruptions (relative to 2010) for heavy rail and motor bus vehicles resulting from the retirement of over-age transit passenger vehicles under the SGR benchmark. Note that the large variation in the percent reduction for bus is a result of the timing of large bus fleet replacements. Also, while the reduction in service disruptions is significant for bus and heavy rail vehicles, some vehicle types (e.g., light and commuter rail) actually show a net increase in service disruptions under the SGR benchmark; this is because the current age distribution for these fleets is skewed toward younger vehicle ages and is not sustainable in the longer term. This effect is the result of the recent development of new light rail and commuter rail systems.

Exhibit 8-27 **Percent Reduction in Revenue Service Disruptions Relative to 2010 for State of Good Repair Benchmark**



Source: Transit Economic Requirements Model.

Low and High Growth Scenarios

The preceding scenario considered the level of investment to bring existing transit assets to a SGR but in doing so did not consider either (1) the cost effectiveness of these investments (investments were not required to pass TERM's benefit-cost test) or (2) the level of expansion investment required to support projected ridership growth. The Low Growth scenario and High Growth scenario address both of these issues. Specifically, these scenarios use the same rules to assess when assets should be rehabilitated or replaced as were applied in the preceding SGR benchmark (e.g., with assets being replaced at condition 2.5), but also require that these preservation and expansion investments pass TERM's benefit-cost test. In general, some reinvestment activities do not pass this test (i.e., have a benefit-cost ratio of less than one), which can

result from low ridership benefits, higher capital or operating costs, or a mix of these factors. Excluding investments that do not pass the benefit-cost test has the effect of reducing total estimated needs.

In addition, the Low and High Growth scenarios also assess transit expansion needs given ridership growth as projected by the Nation's MPOs (low growth) and based on the average annual compound rate as experienced over the last 15-year period (high growth). For the expansion component of this scenario, TERM assesses the level of investment required to maintain current vehicle occupancy rates (at the agency-mode level) subject to the rate of projected growth in transit demand in that UZA and also subject to the proposed expansion investment passing TERM's benefit-cost test.

Low Growth Assumption

The Low Growth scenario is intended to provide a lower bound on the level of investment required to maintain current service performance (as measured by transit vehicle capacity utilization) as determined by a relatively low rate of growth in travel demand. In particular, this Low Growth scenario relies on growth in travel demand as projected by a sample of the MPOs (representing the Nation's 30 largest UZAs and a sample of smaller UZAs). When aggregated across the Nation's UZAs (and corrected for differences in transit demand by UZA), this source yields a national average annual growth rate of 1.4 percent over the 20-year period from 2010 to 2030. (This represents the weighted average growth rate at the national level. In practice, the ridership growth rates applied by TERM vary by UZA based on the growth projections obtained from that UZA's MPO.) This projected rate of growth is less than the 2.2-percent trend rate experienced over the 15 year period from 1995 to 2010 (as utilized by the High Growth scenario presented below), but is higher than the 1.2 percent trend rate of growth in urban population over the decade from 2000 to 2010 (a primary driver of transit ridership).

The MPO projections are considered low (or at least conservative) for the following reasons. First, MPO transit demand projections are financially constrained (i.e., projected ridership growth is limited by the expected capacity to fund expansion projects) and, hence, these projections are lower than the potential for increased ridership demand if funding were unconstrained. Second, as discussed further in Chapter 9, the historical rate of increase in transit ridership and transit passenger miles have generally exceeded MPO growth projections for these same time periods, again tending to characterize the MPO growth projections as relatively low or conservative.

High Growth Assumption

The High Growth scenario provides a higher bound on the level of investment required to maintain current service performance as determined by a relatively high rate of growth in travel demand. In particular, the High Growth scenario relies on the trend rate of growth in transit passenger miles over the period 1995 through 2010 as reported to the NTD. When calculated across all transit operators, this historical trend rate of growth converts to a national average compound annual growth rate of 2.2 percent during this time period. Similar to the MPO growth rates in the Low Growth scenario, the 15-year trend growth rates applied by TERM for the High Growth scenario also vary by UZA either based on the actual trend rates of growth experienced by each UZA (for UZAs close to or higher than 1 million in population) or based on the average for UZAs of comparable size in the same geographic region. This rate is considered relatively high primarily due to the unusually high rate of growth in ridership experienced over the period from roughly 2006 to 2010, partly in response to high fuel prices.

Low and High Growth Scenario Needs

TERM's projected annual average capital investment needs under the Low and High Growth scenarios—including those for both asset preservation and asset expansion—is presented in *Exhibit 8-28*.

Exhibit 8-28 **Low and High Growth Scenarios: Average Annual Investment by Asset Type, 2010–2030 (Billions of 2010 Dollars)**

Asset Type	Lower Growth			Higher Growth		
	Preservation	Expansion	Total	Preservation	Expansion	Total
Rail						
Guideway Elements	$2.7	$0.7	$3.5	$2.8	$0.9	$3.6
Facilities	$0.9	$0.1	$0.9	$0.9	$0.1	$1.0
Systems	$3.4	$0.2	$3.5	$3.4	$0.2	$3.6
Stations	$1.8	$0.5	$2.2	$1.8	$0.6	$2.4
Vehicles	$2.5	$0.8	$3.3	$2.5	$1.3	$3.8
Other Project Costs	$0.0	$0.7	$0.7	$0.0	$0.9	$0.9
Subtotal Rail*	**$11.2**	**$2.9**	**$14.2**	**$11.3**	**$4.0**	**$15.3**
Nonrail						
Guideway Elements	$0.4	$0.1	$0.5	$0.4	$0.1	$0.5
Facilities	$1.4	$0.3	$1.7	$1.4	$0.6	$2.0
Systems	$0.2	$0.0	$0.3	$0.2	$0.1	$0.3
Stations	$0.1	$0.0	$0.1	$0.1	$0.0	$0.1
Vehicles	$4.0	$1.2	$5.3	$4.1	$2.3	$6.3
Other Project Costs	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Subtotal Nonrail*	**$6.1**	**$1.7**	**$7.8**	**$6.1**	**$3.1**	**$9.2**
Total Investment*	**$17.3**	**$4.6**	**$22.0**	**$17.4**	**$7.1**	**$24.5**

** Note that totals may not sum due to rounding.*

Source: Transit Economic Requirements Model.

Lower Growth Needs

Assuming the relatively low ridership growth in the Low Growth scenario, total investment needs for both system preservation and expansion are estimated to average roughly $22.0 billion each year for the next two decades. Of this amount, roughly 79 percent are for preservation of existing assets and approximately $11 billion is associated with preservation of existing rail infrastructure alone. Note that the $1.2 billion difference between the $18.5 billion in annual preservation needs under the SGR benchmark and the $17.3 billion in preservation needs under the Low Growth scenario is entirely due to the application of TERM's benefit-cost test under the Low Growth scenario. Finally, expansion needs in this scenario total $4.6 billion annually, with 63 percent of that amount associated with rail expansion costs.

Higher Growth Needs

In contrast, total investment needs under the High Growth scenario are estimated to be $24.5 billion annually, a 12 percent increase over the total investment needs under the Low Growth scenario. The High Growth scenario total includes $17.4 billion for system preservation and an additional $7.1 billion for system expansion. Note that system preservation costs are higher under the High Growth scenario because the higher growth rate leads to a larger expansion of the asset base as compared to the Low Growth scenario. Under this scenario, investment in expansion of rail assets is still larger than that for nonrail expansion (56 percent for rail and 44 percent for non-rail). However, under the High Growth scenario rail takes only 56 percent of total expansion investment versus 63 percent of expansion needs under the Low Growth scenario. Overall, total expansion investment needs are roughly 53 percent higher for the High Growth scenario than for the Low Growth scenario (which is somewhat consistent with the high growth rate at 2.2 percent being approximately 60 percent higher than the low growth rate of 1.4 percent).

Impact on Conditions and Performance

The impact of the Low and High Growth Rate preservation investments on transit conditions is essentially the same as that already presented for the SGR benchmark in *Exhibit 8-25* and *Exhibit 8-26*. As noted

above, these scenarios use the same rules to assess when assets should be rehabilitated or replaced as were applied in the SGR benchmark (e.g., with assets being replaced at condition rating 2.5). In terms of asset conditions, the primary difference between the SGR benchmark and the Low and High Growth scenarios relates to: (1) TERM's benefit-cost test not applying to the SGR benchmark (leading to higher SGR preservation needs overall) and (2) the Low and High Growth scenarios having some additional needs for the replacement of expansion assets with short service lives. Together, these impacts tend to work in opposite directions with the result that the rate of drawdown in the investment backlog and the elimination of assets exceeding their useful life are roughly comparable for each of these three scenarios.

Similarly, the impact of the Low and High Growth rate expansion investments on transit performance was considered in *Exhibit 8-23.* That analysis demonstrated the significant difference in the level of ridership growth supported by the High Growth scenario as compared with either the current level of expenditures ($5.4 billion in 2010 for UZAs over 1 million) or the rate of growth supported under the Low Growth scenario.

Scenario Benefits Comparison

Finally, this subsection summarizes and compares many of the investment benefits associated with each of the four analysis scenarios considered above. While much of this comparison is based on measures already introduced above, this discussion also considers a few additional investment impact measures. These comparisons are presented in *Exhibit 8-29*. Note that the first column of data in *Exhibit 8-29* presents the current values for each of these measures (as of 2010). The subsequent columns present the estimated future values in 2030 assuming the levels, allocations, and timing of expenditures associated with each of the four investment scenarios.

Exhibit 8-29 includes the following measures:

- **Average Annual Expenditures (billions of dollars):** This amount is broken down into preservation and expansion expenditures.
- **Condition of Existing Assets:** This analysis only considers the impact of investment funds on the condition of those assets currently in service.

  Average Physical Condition Rating: The weighted average condition of all existing assets on TERM's condition scale of 5 (excellent) through 1 (poor).

  Investment Backlog: The value of all deferred capital investment, including assets exceeding their useful lives and rehabilitation activities that are past due (this value can approach but never reach zero due to assets continually aging with some exceeding their useful life). The backlog is presented here both as a total dollar amount and also as a percent of the total replacement value of all U.S. transit assets.

  Backlog Ratio: The ratio of the current investment backlog to the annual level of investment required to maintain normal annual capital needs once the backlog is eliminated.

- **Performance Measures:** The impact of investments on U.S. transit ridership capacity and system reliability.

  New Boardings Supported by Expansion Investments: The number of additional riders that transit systems can carry without a loss in performance (given the projected ridership assumptions for each scenario).

  Carbon Dioxide (CO_2) Emissions Avoided (millions of metric tons): Potential reduction in CO_2 emissions from providing the additional transit rider carrying capacity (assumes that riders would otherwise use other modes of travel, including automobiles).

Exhibit 8-29 Scenario Investment Benefits Scorecard

Measure	Baseline 2010 Actual Spending, Conditions and Performance	Scenarios for 2030: Sustain 2010 Spending	SGR	Low Growth	High Growth
Average Annual Expenditures (Billions of 2010 Dollars)					
Preservation	$10.3	$10.3	$18.5	$17.3	$17.4
Expansion	$6.2	$6.2	NA	$4.6	$7.1
Total	**$16.5**	**$16.5**	**$18.5**	**$22.0**	**$24.5**
Conditions (Existing Assets)					
Average Physical Condition Rating	3.75	3.39	3.54	3.54	3.54
Investment Backlog (Billions of Dollars)	$85.9	$141.7	$0.0	$0.0	$0.0
Investment Backlog (% of Replacement Costs)	12.6%	20.9%	0.0%	0.0%	0.0%
Backlog Ratio[1]	6.1	10.0	0.0	0.0	0.0
Performance					
Ridership Impacts of Expansion Investments (2010)					
New Boardings Supported by Expansion (Billions)	NA	4.6	NA	3.0	5.4
CO_2 Emissions Avoided (Millions of Metric Tons)	NA	3.0	NA	1.9	3.5
Fleet Performance					
Revenue Service Disruptions per Thousand PMT	9.5	10.5	9.3	9.2	9.3
Fleet Maintenance Cost per Revenue Vehicle Mile	$1.75	$1.86	$1.74	$1.73	$1.73
Other Benefits					
Job Years Impact (Thousands)[2]					
Operating and Maintenance	1,201.7	1,620.6	1,201.7	1,549.3	1,828.4
Capital	264.3	264.3	295.4	351.3	392.6
Total Annual Job Years Supported	**1,466.0**	**1,884.9**	**1,497.0**	**1,900.6**	**2,221.0**
GDP Impact (Billions of Dollars)					
Operating and Maintenance	$71.1	$95.9	$71.1	$91.7	$108.2
Capital	$22.0	$22.0	$24.6	$29.3	$32.7
Total Annual Incremental Impact	**$93.1**	**$117.9**	**$95.7**	**$120.9**	**$140.9**

[1] The backlog ratio is the ratio of the current investment backlog to the annual level of investment to maintain SGR once the backlog is eliminated.

[2] Includes direct, indirect, and induced impacts.

Source: Transit Economic Requirements Model.

Revenue Service Disruptions per Passenger Mile Traveled: Number of disruptions to revenue service per million passenger miles.

Fleet Maintenance Cost per Vehicle Revenue Mile: Fleet maintenance costs tend to increase with fleet age (or reduced asset condition). This measure estimates the change in fleet maintenance costs expressed in a per-revenue-vehicle-mile basis.

- **Other Benefits:** Impacts other than those to transit conditions and performance. The jobs and Gross Domestic Product (GDP) impacts considered here were determined using an input-output analysis.

  Jobs Impacts: The number of job years associated with both transit mode operations and ongoing capital investment (both preservation and expansion), including direct, indirect, and induced job years.

Each $1 million invested in transit operation activities is estimated to support 33 job years while each $1 million invested in transit capital investments supports 16 job years.

GDP Impacts: The impact on GDP associated with both transit mode operations and ongoing capital investment (both preservation and expansion), including direct, indirect, and induced impacts. Each $1 invested in transit operation activities is estimated to generate $0.95 in additional GDP while each $1 invested in transit capital investments generates $0.33 in additional GDP.

Scorecard Comparisons

A review of the scorecard results for each of the four investment scenarios reveals the impacts discussed below.

Preservation Impacts

Continued reinvestment at the 2010 level is likely to yield a decline in overall asset conditions, an increase in the size of the investment backlog, and an increase in both service disruptions per million passenger miles and in maintenance costs per vehicle revenue mile. In contrast, with the exception of overall asset conditions, each of these measures is projected to improve under the SGR, Low Growth, and High Growth scenarios, each of which project roughly comparable levels of required capital reinvestment expenditures. Note that the overall condition rating measure of 3.54 under these last three investment scenarios represents a sustainable, long-term condition level for the Nation's existing transit assets over the long term (in contrast to the current measure of roughly 3.8, which would be difficult to maintain in the long term without replacing many asset types prior to the conclusion of their expected useful lives).

Expansion Impacts

While continued expansion investment at the 2010 level appears sufficient to support a relatively low rate of increase in transit ridership, recent historical rates of growth suggest that a significantly higher rate of expansion investment is required to avoid a decline in overall transit performance (e.g., in the form of increased crowding on high utilization systems). Higher rates of transit expansion investment, as required to support higher transit ridership growth or through a shift from auto travel to transit, can also help yield reductions in CO_2 emissions. Finally, higher rates of expansion investment also tend to support higher direct, indirect and induced impacts on jobs and other economic activity related to transit operations, construction, and rehabilitation activities.

CHAPTER 9

Supplemental Scenario Analysis

Highway Supplemental Scenario Analysis

This section explores the implications of the highway investment scenarios considered in Chapter 8, starting with a comparison of the scenario investment levels relative to those presented in previous C&P reports. For a longer-term perspective, this section also looks back to the 20-year projections presented in the 1989 C&P Report relative to actual outcomes in terms of system conditions and performance.

This section also includes an illustration of the impact of alternative rates of future inflation on the constant dollar scenario investment levels presented in Chapter 8, and explores alternative assumptions concerning the timing of investment over the 20-year analysis period. A subsequent section within this chapter provides supplementary analysis regarding the transit investment scenarios.

Comparison of Scenarios With Previous Reports

Each edition of this report presents various projections of travel growth, pavement conditions, and bridge conditions under different scenarios. The projections cover 20 year periods, beginning the first year after the data presented on current conditions and performance. While the scenario names and criteria have varied over time, the C&P Report has traditionally included highway investment scenarios corresponding in concept to **Maintain Conditions and Performance** scenario and **Improve Conditions and Performance** scenario presented in Chapter 8.

Comparison With 2010 C&P Report

As discussed in Chapter 8, the measures targeted by the **Maintain Conditions and Performance** scenario have been changed; the 2010 C&P Report version of this scenario attempted to maintain average speed and the bridge investment backlog, but the current version targets average pavement roughness, average delay and the average bridge sufficiency rating. However, the fundamental purpose of the scenario is to identify a level of investment associated with keeping overall conditions and performance in 20 years at roughly base-year levels. The criteria used to define the **Improve Conditions and Performance** scenario remains unchanged from the 2010 C&P Report; the only difference is that the 2010 C&P Report projected the impact of investment for 2009 through 2028, rather than the 2011 through 2030 period covered in the current edition.

As discussed in Chapter 6, highway construction costs as measured by the Federal Highway Administration's (FHWA's) National Highway Construction Cost Index decreased by 18.0 percent between 2008 and 2010. Consequently, adjusting the 2010 C&P Report's scenario figures from 2008 dollars to 2010 dollars causes them to appear smaller. As shown in *Exhibit 9-1,* the 2010 C&P Report estimated the average annual investment level in the scenario comparable to the current **Maintain Conditions and Performance** scenario at $101.0 billion; adjusting for inflation (or, in this discussion, deflation) decreases this amount to $82.8 billion in 2010 dollars. The comparable amount for the **Maintain Conditions and Performance** scenario presented in Chapter 8 of this edition is $86.3 billion, approximately **4.2 percent higher**.

The average annual investment level in the 2010 C&P Report scenario comparable to the current **Improve Conditions and Performance** scenario was $170.1 billion; adjusting for inflation decreases this amount to $139.4 billion in 2010 dollars. The comparable amount for the current **Improve Conditions and Performance** scenario presented in Chapter 8 of this edition is $145.9 billion, approximately **4.7 percent higher**.

Exhibit 9-1 Selected Highway Investment Scenario Projections Compared With Comparable Data From the 2010 C&P Report (Billions of Dollars)

Highway and Bridge Scenarios—All Roads	2009–2028 Projection (Based on 2008 Data)		2011–2030 Projection
	2010 C&P Report (Billions of 2008 Dollars)	Adjusted for Inflation[1] (Billions of 2010 Dollars)	(Billions of 2010 Dollars)
Maintain Conditions and Performance scenario[2]	**$101.0**	**$82.8**	**$86.3**
Improve Conditions and Performance scenario	**$170.1**	**$139.4**	**$145.9**

[1] The investment levels for the highway and bridge scenarios were adjusted for inflation using the FHWA National Highway Construction Cost Index (NHCCI).

[2] In the 2010 C&P report, the HERS component of this scenario focused on maintaining average speed, rather than representing the average of the cost associated with maintaining average delay and the cost associated with maintaining average pavement condition; the NBIAS component of the scenario focused on maintaining the bridge investment backlog, rather than maintaining the average sufficiency rating for bridges.

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

The changes in the scenario findings in this report relative to the 2010 C&P Report are also partially attributable to changes in the underlying characteristics, conditions, and performance of the bridge system reported in Chapters 2 and 3, as well as to changes in the analytical methodology in the National Bridge Investment Analysis System (NBIAS) model. As noted in Chapter 7, the version of the Highway Economic Requirements System (HERS) used for this report was not significantly different from that used in the 2010 C&P Report, and the same underlying Highway Performance Monitoring System (HPMS) dataset was used. The main differences within the HERS analysis related to updated model parameter values.

Comparisons of Implied Funding Gaps

Exhibit 9-2 compares the funding gaps implied by the analysis in the present report with those implied by previous C&P report analyses. Each such gap is measured as the percentage by which the average annual investment estimated for a specific scenario exceeds the base-year level of investment. The scenarios examined are this report's **Maintain Conditions and Performance** and **Improve Conditions and Performance** scenarios, and their counterparts in previous C&P reports.

For each of the reports identified, actual spending in the base year for that report has been below the estimate of the average annual investment level required to maintain conditions and performance at base-year levels over 20 years. In the current report, the gap between these amounts, negative 13.9 percent, is dramatically different than in the 2010 C&P Report when it was positive 10.8 percent. This indicates that 2010 spending was greater than the level of spending identified for the **Maintain Conditions and Performance** scenario. This is partly due to the increase in funding under the American Recovery and Reinvestment Act, but largely due to the fact that construction costs have declined, making it cheaper to meet the scenario's objectives.

Changes in the actual capital spending by all levels of government combined can substantially alter these spending gaps, as can sudden, large swings in construction costs. The large increase in the gap between base-year spending and the primary "Maintain" scenario presented in the 2008 C&P Report coincided with a large increase of construction costs experienced between 2004 and the 2006 base year for that report. The decreases in the gaps presented in the 2010 and 2012 editions coincided with declines in construction costs since their 2006 peak.

The differences among C&P report editions in the implied gaps reported in *Exhibit 9-2* do not constitute a consistent indicator of change over time in how effectively highway investment needs are addressed. The FHWA continues to enhance the methodology used to determine scenario estimates for each edition of

the C&P report in order to provide a more comprehensive and accurate assessment. In some cases, these refinements have increased the level of investment in one or both of the scenarios (the "Maintain" or "Improve" scenarios, or their equivalents); other refinements have reduced this level.

Exhibit 9-2 Comparison of Average Annual Highway and Bridge Investment Scenario Estimates With Base Year Spending, 1997 to 2013 C&P Reports

Report Year	Relevant Comparison	Percent Above Base-Year Spending	
		Primary "Maintain" Scenario*	Primary "Improve" Scenario*
1997	Average annual investment scenario estimates for 1996 through 2015 compared with 1995 spending	21.0%	108.9%
1999	Average annual investment scenario estimates for 1998 through 2017 compared with 1997 spending	16.3%	92.9%
2002	Average annual investment scenario estimates for 2001 through 2020 compared with 2000 spending	17.5%	65.3%
2004	Average annual investment scenario estimates for 2003 through 2022 compared with 2002 spending	8.3%	74.3%
2006	Average annual investment scenario estimates for 2005 through 2024 compared with 2004 spending	12.2%	87.4%
2008	Average annual investment scenario estimates for 2007 through 2026 compared with 2006 spending	34.2%	121.9%
2010	Average annual investment scenario estimates for 2009 through 2028 compared with 2008 spending	10.8%	86.6%
2013	Average annual investment scenario estimates for 2011 through 2030 compared with 2010 spending	-13.9%	45.7%

** Amounts shown correspond to the primary investment scenario associated with maintaining or improving the overall highway system in each C&P report; the definitions of these scenarios are not fully consistent between reports. The values shown for this report reflect the **Maintain Conditions and Performance** and the **Improve Conditions and Performance** scenarios. Negative numbers signify that the investment scenario estimate was lower than base year spending.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

Comparison of Scenario Projections in 1991 C&P Report to Actual Expenditures, Conditions, and Performance

The highway component of the C&P report is part of a series dating back to the 1968 *National Highway Needs* report to Congress.

The *1991 Status of the Nation's Highways and Bridges: Condition and Performance* report to Congress (1991 C&P Report) is the most recent edition for which the 20-year forecast period has ended. This section explores the predictions made in the 1991 report for the year 2009 relative to what actually occurred in terms of pavement conditions, bridge conditions, and operational performance, taking into account actual investment and travel growth that has occurred.

Comparing such past predictions with actual results can be very informative in placing the projections from the current edition in their proper context. However, direct comparisons of results across different C&P editions pose challenges for multiple reasons, including differences in base-year conditions and analysis periods, changes in analytical models, and changes in scenario definitions.

1991 C&P Report Scenario Definitions

Similar to the current edition, the 1991 C&P Report estimated two scenarios for future investment requirements: **Improve 1989 Conditions and Performance** and **Maintain 1989 Conditions and Performance**. The investment levels presented were stated in constant 1989 dollars.

The 1991 C&P Report develops scenarios based on engineering standards that were applied uniformly nationwide without the consideration of the relative importance of specific facilities, regional variation, or other policy considerations. The scenario predictions were designed to provide general financial and performance benchmarks and were a basis for development and evaluation of policy and program options.

Improve 1989 Conditions and Performance

The **Improve 1989 Conditions and Performance** scenario estimated the costs associated with addressing deficiencies relative to a set of engineering-based minimum standards for physical conditions and performance. The goal of this scenario was to improve conditions and performance across all functional systems on a uniform basis nationwide, for both urban and rural, even as travel demand increased at a rate of 2.5 percent annually for 20 years. However, the 1991 C&P Report indicates that a cap on the width of individual highway sections was imposed, which resulted in a set of unmet capacity needs to the extent to which operational performance in larger urbanized areas could not be maintained. The scenario reflected estimated annual capital savings from an aggressive traffic management program.

Unlike the present edition, which prioritizes investment based on benefit-cost analysis, the 1991 C&P Report acknowledges that the scenarios did not involve priorities regarding cost-effectiveness and was not intended to represent an optimum recommended investment strategy. Instead, the scenario was intended to provide a framework for policy development by establishing a measure of the total capital costs of providing a desirable level of highway and bridge infrastructure on all facilities, assuming a future travel demand growth of 2.5 percent annually.

Maintain 1989 Conditions and Performance

The **Maintain 1989 Conditions and Performance** scenario estimated the cost of maintaining both current overall physical conditions and current levels of performance as traffic increased over a 20-year period. The 1991 C&P Report notes that overall system performance would not be maintained in the largest urbanized areas assuming a 2.5 percent annual growth in vehicle miles traveled (VMT).

Comparison of Scenario Projections in 1991 C&P Report to Actual Spending

Exhibit 9-3 shows the estimated average annual and cumulative 20-year highway and bridge needs associated with the two scenarios presented in the 1991 C&P Report. The cumulative values are also adjusted for

Exhibit 9-3 1991 C&P Report Highway and Bridge Investment Scenario Estimates and Cumulative Spending, 1990 Through 2009

	1990–2009 Projection From 1991 C&P Report		Adjusted for Inflation
	Average Annual (Billions of 1989 Dollars)	Cumulative 20 Years (Billions of 1989 Dollars)	Cumulative 20 Years (Billions of 2010 Dollars)
20-Year Highway Capital Investment Scenarios (Assuming 2.5-Percent Annual VMT Growth from 1989 to 2009)			
Improve Conditions and Performance Scenario	$74.9	$1,498.0	**$2,422.2**
Maintain Conditions and Performance Scenario	$45.7	$914.0	**$1,477.9**
Actual 20-Year Highway Capital Investment (VMT Grew 1.74 Percent per Year from 1989 to 2009)			
Cumulative Capital Outlay, 1990 through 2009*			**$1,418.9**

** Highway capital outlay by all levels of Government combined totaled $1.2111 trillion in nominal dollar terms over the 20-year period from 1990 through 2009. This equates to $1.4189 trillion in constant 2010 dollars.*

Sources: 1991 Status of the Nation's Highways and Bridges: Conditions and Performance Report to Congress; Highway Statistics, various years, Tables HF-10A, HF-10, PT-1, and SF-12A; and unpublished FHWA data.

inflation to 2010 dollars using the FHWA Composite Bid Price Index (BPI) through the year 2006 and the new FHWA National Highway Construction Cost Index (NHCCI) for subsequent years.

The 1991 C&P Report estimated the average annual cost of the **Improve 1989 Condition and Performance** scenario at $74.9 billion for 1990 through 2009, assuming a 2.5 percent VMT growth rate.

The average annual cost to **Maintain 1989 Condition and Performance** on existing roads and bridges through 2009 was estimated at $45.7 billion, again assuming a 2.5 percent VMT growth rate.

The cumulative 20-year value inflated to 2010 dollars for the **Improve 1989 Condition and Performance** scenario equates to $2.422 trillion. The cumulative value of the **Maintain Conditions and Performance** scenario in 2010 dollars equates to $1.478 trillion, which is within 4 percent of the actual cumulative capital outlay of $1.419 trillion, stated in constant 2010 dollars.

Assumptions about future VMT growth are a critical input to the investment scenario. The actual rate of VMT growth over the 20-year period from 1989 to 2009 was 1.74 percent per year, well below the 2.5 percent annual VMT growth forecast used in the 1991 C&P Report scenarios.

The 1991 C&P Report included sensitivity analysis that assumed a higher average annual VMT growth rate of 3.0 percent for some of the major components of the two investment scenarios, which increased their cost by 13 percent (Improve) to 17 percent (Maintain). However, the 1991 C&P Report did not conduct any tests of VMT growth rates lower than 2.5 percent. As a result, although these analyses demonstrate that the scenarios were significantly affected by the VMT growth rate assumption, it would not be safe to assume that the reductions in scenario costs associated with lower VMT growth rates would be proportional to these increases in scenario costs associated with higher VMT growth forecasts. If the forecasts had been developed assuming a 1.74-percent average annual growth rate, the cost associated with both scenarios would have been lower.

Comparison of Scenario Projections in 1991 C&P Report to Actual Outcomes

The 1991 C&P Report included projections for measures of pavement condition, bridge condition, and operational performance. As was demonstrated in *Exhibit 9-3*, actual capital spending from 1990 through 2009 was slightly lower than the investment levels associated with the **Maintain Conditions and Performance** scenario**,** which suggests that overall highway and bridge system conditions would have deteriorated slightly relative to 1989. However, because the VMT growth rate assumed in that scenario was significantly higher than what actually occurred from 1989 to 2009, the investment levels associated with that scenario were overstated to some degree. Consequently, improvements to some measures of conditions and performance relative to 1989 could reasonably be expected.

Exhibit 9-4 compares the percentage of pavement in good condition by facility type; bridge deficiencies; and travel under congested condition for 1989, 2008, and 2010. The pavement condition ratings presented in the 1991 C&P Report were based on a subjective evaluation of overall pavement quality which has subsequently been replaced by a more objective measure of pavement ride quality. However, the percentage of pavements in good condition is roughly comparable between the two reports. Since 1989, the percent of good pavement mileage has increased for the rural functional classes shown, except for rural major collectors. In contrast, for urban highways, the percent of good pavement mileage has decreased for all functional classes shown except urban Interstate.

The percentage of bridges classified as structurally deficient or functionally obsolete is still defined in a manner comparable to that in the 1991 C&P Report. There has been improvement since 1989, as the percentage of structurally deficient bridges has been cut sharply and reductions in the percentage of functionally obsolete bridges have been achieved.

Exhibit 9-4 Selected Pavement, Bridge, and Congestion Metrics, 1989, 2008, and 2010

Scenario and Comparison Parameter	1989	2008	2010
Percent of "Good" Pavement Mileage[1]			
Rural Interstate	58.2%	78.2%	73.8%
Rural Other Principal Arterial	51.9%	66.5%	N/A
Rural Minor Arterial	45.5%	53.3%	49.7%
Rural Major Collector	34.2%	34.0%	28.7%
Urban Interstate	57.4%	61.4%	63.2%
Urban Other Freeway & Expressway	52.7%	50.6%	48.0%
Urban Other Principal Arterial	42.7%	27.4%	26.7%
Urban Minor Arterial	40.7%	32.1%	22.2%
Urban Collector	31.3%	28.3%	N/A
Bridge Deficiencies[2]			
Percent Structurally Deficient	23.2%	11.9%	11.5%
Percent Functionally Obsolete	15.9%	13.3%	12.8%
Total Percent Deficient	39.2%	25.2%	24.3%
Operational Performance[3]			
Percent of Travel Under Congested Conditions	20.6%	26.3%	26.2%

[1] The 1991 C&P Report classified pavements as "Good" if they had a Pavement Serviceability Rating (PSR) of 3.5 or higher on a scale of 5.0. The current terminology reflected in Chapter 3 describes pavements as having "Good Ride Quality" if they have a reported IRI of 95 inches per mile or lower (or a PSR of 3.5 or higher if IRI is not available). Subtotals and Totals are not provided because the 1991 C&P Report did not include them. N/A is shown for functional classes that were split starting in 2010.

[2] See Chapter 3 for more information on these measures.

[3] See Chapter 5 for more information on this measure.

Sources: Sources: 1991 C&P Report, Highway Performance Monitoring System, National Bridge Inventory, and Texas Transportation Institute.

The operational performance measures presented in the 1991 C&P Report are not consistent with those in the current edition. However, the Texas Transportation Institute has computed a fully comparable historic time series for a metric presented in Chapter 5: the percent of travel occurring under congested conditions. Based on this measure, congestion has worsened since 1989.

Although these types of rough comparisons of individual conditions and performance measures are not sufficiently robust to make definitive statements of the validity of the analyses presented in the 1991 C&P Report, actual trends over the forecast period do not appear to be wildly inconsistent with the report's findings, taking into account the lower than projected growth in VMT. Because actual capital investment over the 20-year period was relatively close to the **Maintain 1989 Conditions and Performance** scenario, it is not surprising that actual performance outcomes were mixed, with pavement condition improving on some functional classes while worsening on others, with bridge conditions improving, and with operational performance deteriorating relative to 1989.

Accounting for Inflation

The analysis of potential future investment/performance relationships in the C&P report has traditionally stated future investment levels in constant dollars, with the base-year set according to the year of the conditions and performance data supporting the analysis. Throughout Chapters 7 and 8, this edition of the C&P report has stated all investment levels in constant 2010 dollars. For some purposes, however, such as comparing investment spending in a particular scenario with nominal dollar revenue projections, one would want to adjust for inflation. Given an assumption about future inflation, one could either convert the C&P report's constant-dollar numbers to nominal dollars or convert the nominal projected revenues to constant 2010 dollars.

Why are the investment analyses presented in this report expressed in constant base-year dollars?

Q&A

The investment/performance models discussed in this report estimate the future benefits and costs of transportation investments in constant-dollar terms. This is standard practice for this type of economic analysis. To convert the model outputs from constant dollars to nominal dollars, it would be necessary to externally adjust them to account for projected future inflation.

Traditionally, this type of adjustment has not been made in the C&P report. Because inflation prediction is an inexact science, adjusting the constant-dollar figures to nominal dollars tends to add to the uncertainty of the overall results and make the report more difficult to use if the inflation assumptions are inaccurate. Allowing readers to make their own inflation adjustments based on actual trends observed subsequent to the publication of the C&P report and/or the most recent projections from other sources is expected to yield a better overall result, particularly in light of the sharp swings in highway construction materials costs in recent years.

The use of constant-dollar figures is also intended to provide readers with a reasonable frame of reference in terms of an overall cost level that they have recently experienced. When inflation rates are compounded for 20 years, even relatively small growth rates can produce nominal dollar values that appear very large when viewed from the perspective of today's typical costs.

Why does this report assume that construction costs measured in constant dollars remain unchanged over the analysis period?

Q&A

Chapter 7 provided the definition of constant dollar measurement that the Office of Management and Budget includes in its guidance on benefit-cost analysis. Under this definition, any price predicted for a future year must be adjusted for the general inflation expected to occur between the base year and the future year, For example, if a future-year price is expected to be $1.10, whereas prices in general are expected to increase 3 percent between the base year and the future year, the price in constant dollars would be calculated as $1.10 divided by 1.03, which is approximately $1.068.

With a few exceptions, this report's analyses of future investments in highways assume that prices entering the HERS model will change by the same percentage as general inflation, as measured by the Consumer Price Index (CPI). Under this assumption, the future price in constant dollars simply equates to the base-year price. As discussed in Chapter 7, the exceptions include the price of motor fuel and the marginal damage cost of CO emissions; as discussed in Chapter 10, the values of travel time savings and of crash reductions are also exceptions.

The costs of highway improvements were not among the exceptions. Typical prices by type of improvement were assumed to increase at the same rate as the CPI, so that base-year prices were applied to future years. One reason for making this simplifying assumption is that, as discussed in Chapter 6, highway construction prices have been volatile in recent years; this suggests that forecasting their future movements relative to the CPI would be challenging. (Motor fuel price have also been volatile, but long-range forecasts are available from the Energy Information Administration.)

Additional challenges to attempting such forecasting include limitations of the historical data on construction prices, as discussed in Appendix D of the 2010 C&P Report. It should be noted that the assumption that construction prices will change at the rate of general inflation may be fairly reasonable on average. As noted in Chapter 6, this report's reading of the historical evidence is that, over the 20-year period from 1990 to 2010, highway construction costs increased 60.5 percent, which is not much different from the 66.8 percent increase in the CPI.

The average annual increase in highway construction costs over the last 20 years (1990 to 2010) was 2.4 percent. Since the creation of the Federal Highway Trust Fund in 1956, the 20-year period with the smallest increase in construction costs was 1980 to 2000, when costs grew by 2.0 percent per year; the largest increase occurred from 1960 to 1980, when costs grew by 7.4 percent per year. From 1986 to 2006, highway construction costs grew by 4.0 percent annually. (Historic inflation rates were determined using the FHWA Composite Bid Price Index through 2006, and the new FHWA National Highway Construction Cost Index from 2006 to 2010; these indices are discussed in Chapter 6.) *Exhibit 9-5* illustrates how the constant dollar figures associated with three of the four systemwide scenarios for highways and bridges

presented in Chapter 8 could be converted to nominal dollars based on two alternative inflation rates of 2.0 percent and 4.0 percent.

The systemwide **Sustain 2010 Spending** scenario presented in Chapter 8 assumes that combined capital spending for highway and bridge improvements would be sustained at its 2010 level in constant-dollar terms for 20 years. Hence, *Exhibit 9-5* shows $100.2 billion of spending in constant 2010 dollars for each year from 2011 through 2030, for a 20-year total of $2.0 trillion. Applying annual inflation in construction costs of 2.0 percent or 4.0 percent would imply a 20-year total in nominal dollars of $2.5 trillion or $3.1 trillion, respectively, for this scenario.

Chapter 8 indicates that achieving the objectives of the systemwide **Maintain Conditions and Performance** scenario would require investment averaging $86.3 billion per year in constant 2010 dollars, equivalent to the level of investment achieved with a reduction of 1.44 percent per year in constant-dollar spending. *Exhibit 9-5* illustrates the application of this real reduction rate, demonstrating how annual capital investment would decrease from $100.1 billion in 2010 to $74.9 billion in 2030, resulting in a 20-year

Exhibit 9-5 Illustration of Potential Impact of Alternative Inflation Rates on Selected Systemwide Investment Scenarios

	Highway Capital Investment (Billions of Dollars)								
	Constant 2010 Dollars*			Nominal Dollars (Assuming 2.0 Percent Annual Inflation)			Nominal Dollars (Assuming 4.0 Percent Annual Inflation)		
Year	Sustain 2010 Spending Scenario	Maintain Conditions & Performance Scenario	Improve Conditions & Performance Scenario	Sustain 2010 Spending Scenario	Maintain Conditions & Performance Scenario	Improve Conditions & Performance Scenario	Sustain 2010 Spending Scenario	Maintain Conditions & Performance Scenario	Improve Conditions & Performance Scenario
2010	$100.2	$100.2	$100.2	$100.2	$100.2	$100.2	$100.2	$100.2	$100.2
2011	$100.2	$98.7	$103.6	$102.2	$100.7	$105.7	$104.2	$102.7	$107.8
2012	$100.2	$97.3	$107.2	$104.2	$101.2	$111.6	$108.3	$105.2	$116.0
2013	$100.2	$95.9	$110.9	$106.3	$101.8	$117.7	$112.7	$107.9	$124.8
2014	$100.2	$94.5	$114.8	$108.4	$102.3	$124.2	$117.2	$110.6	$134.3
2015	$100.2	$93.2	$118.7	$110.6	$102.8	$131.1	$121.9	$113.3	$144.5
2016	$100.2	$91.8	$122.8	$112.8	$103.4	$138.3	$126.8	$116.2	$155.4
2017	$100.2	$90.5	$127.1	$115.1	$103.9	$146.0	$131.8	$119.1	$167.3
2018	$100.2	$89.2	$131.5	$117.4	$104.5	$154.1	$137.1	$122.0	$180.0
2019	$100.2	$87.9	$136.0	$119.7	$105.0	$162.6	$142.6	$125.1	$193.6
2020	$100.2	$86.6	$140.7	$122.1	$105.6	$171.6	$148.3	$128.2	$208.3
2021	$100.2	$85.4	$145.6	$124.6	$106.1	$181.1	$154.2	$131.4	$224.2
2022	$100.2	$84.1	$150.7	$127.0	$106.7	$191.1	$160.4	$134.7	$241.2
2023	$100.2	$82.9	$155.9	$129.6	$107.3	$201.6	$166.8	$138.1	$259.5
2024	$100.2	$81.7	$161.3	$132.2	$107.8	$212.8	$173.5	$141.5	$279.2
2025	$100.2	$80.5	$166.8	$134.8	$108.4	$224.5	$180.4	$145.1	$300.5
2026	$100.2	$79.4	$172.6	$137.5	$109.0	$236.9	$187.6	$148.7	$323.3
2027	$100.2	$78.2	$178.6	$140.3	$109.6	$250.0	$195.1	$152.4	$347.8
2028	$100.2	$77.1	$184.7	$143.1	$110.1	$263.9	$202.9	$156.2	$374.3
2029	$100.2	$76.0	$191.1	$145.9	$110.7	$278.5	$211.1	$160.1	$402.7
2030	$100.2	$74.9	$197.8	$148.9	$111.3	$293.8	$219.5	$164.1	$433.3
Total	**$2,003.5**	**$1,725.9**	**$2,918.6**	**$2,482.7**	**$2,118.3**	**$3,697.1**	**$3,102.3**	**$2,622.6**	**$4,717.9**
	0.00%	**-1.44%**	**3.46%**	**Constant Dollar Growth Rate**					
	$100.2	**$86.3**	**$145.9**	**Average Annual Investment Level in Constant 2010 Dollars**					

** Based on average annual investment levels and annual constant dollar growth rates identified in* Exhibit 8-2.

Source: FHWA staff analysis.

(2011 to 2030) total of $1.7 trillion in constant 2010 dollars. A 2.0-percent inflation rate applied to these constant-dollar estimates would produce a 20-year cost of $2.1trillion in nominal dollar terms, while a 4.0-percent inflation rate results in a 20-year nominal dollar cost of $2.6 trillion.

The compounding impacts of inflation are even more evident in the figures for the systemwide **Improve Conditions and Performance** scenario presented in *Exhibit 9-5*. As described in Chapter 8, this scenario assumes 3.46 percent growth in constant-dollar highway capital spending per year in order to address all potentially cost-beneficial highway and bridge improvements by 2030. The $145.9-billion average annual investment level associated with this scenario equates to a 20-year investment level of $2.9 trillion in constant 2010 dollars. Adjusting this figure to account for inflation of 2.0 percent or 4.0 percent would translate into 20-year nominal dollar costs of $3.7 trillion or $4.7 trillion, respectively.

Over any 20 year period, construction costs will increase despite the occasional year-to-year drops sometimes experienced. Using a low inflation rate of 2.0 percent adds between 23 and 27 percent to the constant dollar estimates for the 20-year period for the three scenarios. Using a higher inflation rate of 4.0 percent requires between 52 and 62 percent of additional funding to meet the needs identified under the three scenarios.

Timing of Investment

The investment/performance analyses presented in this report focus mainly on how alternative average annual investment levels over 20 years might impact system performance at the end of this period. Within this period, system performance can be significantly influenced by the timing of investment. Consistent with the approach in the 2008 C&P Report, and as discussed in Chapter 7, the analyses in the present edition assume that any change from the 2008 level of combined investment per year by all levels of government would occur gradually and at a constant percent rate. However, some previous editions used different approaches. The HERS 2006 C&P Report assumed that combined investment would immediately jump to the average annual level being analyzed, then remain fixed at that level for 20 years. The HERS analyses presented in the 2004 C&P Report were tied directly to alternative benefit-cost ratio (BCR) cutoffs rather than to particular levels of investment in any given year. At higher spending levels, this approach resulted in a significant front-loading of capital investment in the early years of the analysis as the existing backlog of potential cost-beneficial investments (discussed above) was addressed, followed by a sharp decline in later years. The analysis did not assume any increase in material and labor costs in response to the sharp increase in the number of highway construction projects.

The discussion below explores the impact of each of these three assumptions about the timing of future investment—ramped spending, flat spending, or BCR-driven spending—on system performance within the 20-year period analyzed. Each of the average annual investment levels analyzed correspond to the baseline HERS analyses for Federal-aid Highways, and the baseline NBIAS analyses for all bridges presented in Chapter 7.

Alternative Timing of Investment in HERS

This section presents information regarding how the timing of investment would impact the distribution of spending among the four 5-year funding periods considered in HERS, and how these spending patterns could potentially impact average pavement conditions (measured using International Roughness Index [IRI]) and delay per VMT. Because the timing of investment is varied for any given capital investment level, the pavement condition and delay per VMT will change.

Alternative Investment Patterns

Exhibit 9-6 indicates how alternative assumptions regarding the timing of investment would impact the distribution of spending among the four 5-year funding periods considered in HERS, and how these

spending patterns could potentially impact pavement condition and delay per VMT. The six investment levels were selected from the baseline ("ramped") HERS analyses for Federal-aid highways presented in Chapter 7. Each investment level is compared across the three investment patterns: baseline (ramped) spending, flat spending, and BCR-driven spending.

Exhibit 9-6 Distribution of Spending Among 5-Year HERS Analysis Periods and Projected Impacts on Average IRI and Average Delay, for Alternative Approaches to Investment Timing

Average Annual HERS-Modeled Capital Investment (Billions of 2010 Dollars)	Percentage of HERS-Modeled Spending Occurring in Each 5-Year Period											
	Baseline				Alternatives							
	Ramped Spending				Flat Spending [1]				BCR-Driven Spending [2]			
	2011 to 2015	2016 to 2020	2021 to 2025	2026 to 2030	2011 to 2015	2016 to 2020	2021 to 2025	2026 to 2030	2011 to 2015	2016 to 2020	2021 to 2025	2026 to 2030
$86.9	18.3%	22.2%	26.9%	32.7%	25.1%	25.1%	25.1%	24.7%	41.2%	18.7%	18.2%	21.9%
$67.8	21.9%	23.9%	26.0%	28.3%	25.0%	25.0%	25.0%	25.0%	37.5%	21.4%	18.9%	22.1%
$60.9	23.7%	24.5%	25.4%	26.4%	25.0%	25.0%	25.0%	25.0%	35.8%	23.3%	19.7%	21.3%
$56.4	**25.0%**	**25.0%**	**25.0%**	**25.0%**	25.0%	25.0%	25.0%	25.0%	34.2%	24.0%	20.4%	21.4%
$51.1	26.8%	25.6%	24.4%	23.2%	25.0%	25.0%	25.0%	25.0%	32.7%	25.4%	21.0%	20.8%
$43.2	30.2%	26.4%	23.1%	20.3%	25.0%	25.0%	25.0%	25.0%	29.5%	26.9%	22.2%	21.4%

Average Annual HERS-Modeled Capital Investment (Billions of 2010 Dollars)	Change in Average IRI Relative to Base Year on Federal-aid Highways											
	Baseline				Alternatives							
	Ramped Spending, Percent Change as of:				Flat Spending, Percent Change as of:				BCR-Driven Spending, Percent Change as of:			
	2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
$86.9	-9.6%	-18.2%	-23.3%	-26.7%	-17.7%	-25.0%	-26.5%	-25.5%	-31.0%	-30.2%	-26.7%	-24.5%
$67.8	-8.1%	-13.7%	-17.1%	-18.0%	-11.4%	-17.0%	-18.5%	-17.7%	-21.9%	-22.6%	-19.8%	-17.6%
$60.9	-7.6%	-11.8%	-14.4%	-14.3%	-8.7%	-13.2%	-14.9%	-14.2%	-17.9%	-19.1%	-16.8%	-14.1%
$56.4	-7.2%	-10.5%	-12.2%	-11.5%	-7.2%	-10.5%	-12.2%	-11.5%	-15.0%	-16.2%	-14.0%	-11.5%
$51.1	-6.5%	-8.7%	-9.2%	-7.6%	-4.8%	-6.9%	-8.0%	-7.5%	-11.4%	-12.5%	-10.4%	-7.9%
$43.2	-5.2%	-5.5%	-4.0%	**0.0%**	-1.1%	-0.8%	-1.2%	0.4%	-4.9%	-5.4%	-3.4%	0.0%

Average Annual HERS-Modeled Capital Investment (Billions of 2010 Dollars)	Change in Average Delay Per VMT Relative to Base Year on Federal-aid Highways											
	Baseline				Alternatives							
	Ramped Spending, Percent Change as of:				Flat Spending, Percent Change as of:				BCR-Driven Spending, Percent Change as of:			
	2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
$86.9	-9.2%	-8.3%	-7.8%	-8.0%	-11.9%	-11.5%	-9.6%	-7.4%	-16.9%	-14.0%	-10.3%	-7.1%
$67.8	-8.6%	-6.5%	-4.4%	-2.4%	-9.7%	-7.9%	-5.4%	-2.2%	-13.3%	-10.4%	-5.8%	-1.7%
$60.9	-8.3%	-5.8%	-2.7%	**0.0%**	-8.8%	-6.3%	-3.0%	0.1%	-11.8%	-8.9%	-4.0%	0.4%
$56.4	-8.0%	-5.2%	-1.5%	1.9%	-8.0%	-5.2%	-1.5%	1.9%	-10.6%	-7.4%	-2.5%	2.3%
$51.1	-7.8%	-4.5%	-0.3%	4.3%	-7.3%	-3.8%	0.0%	4.2%	-9.5%	-6.0%	-0.9%	4.7%
$43.2	-7.5%	-3.2%	2.0%	7.6%	-6.1%	-1.6%	3.0%	7.4%	-7.2%	-3.1%	2.3%	7.6%

[1] The shaded values identified for the row labeled $86.9 billion actually reflect a lower average annual investment level of $86.5 billion, as HERS did not find a sufficient pool of cost-beneficial potential investments to spend the full amount in the last funding period.

[2] Each percentage distribution shown corresponds to a HERS analysis assuming investment up to a minimum benefit-cost ratio cutoff point (not shown) which was set at a level such that 20-year spending would be consistent with the average annual spending level shown. The shaded values for the row labeled $86.9 billion are actually based on a lower average annual investment level of $86.5 billion, as spending more than that amount would have required investing in improvements with a BCR lower than 1.0 (which HERS won't do).

Source: Highway Economic Requirements System.

For the baseline (ramped) analyses, the distribution of spending among funding periods is driven by the annual constant dollar spending growth rate assumed; for higher growth rates, a smaller percentage of a total 20-year investment would occur in the first 5 years.

The flat spending alternative is linked directly to the average annual investment levels associated with each of the baseline analyses; as shown in the top section of *Exhibit 9-6*, because spending would remain the same in each of the 20 years, the distribution of spending within each 5-year period makes up exactly one-quarter of the total. For example, when HERS-modeled capital investment spending is sustained at the base-year level of $56.4 billion, the results of the ramped spending and flat spending alternatives are identical. (Spending is flat when its growth rate is zero.) As noted in *Exhibit 9-6*, although HERS finds an average annual investment level of $86.9 billion to be cost-beneficial assuming ramped spending, the model identifies only $86.5 billion of cost-beneficial investment assuming flat spending.

The BCR-driven spending percentages identified in *Exhibit 9-6* represent the distribution of spending that would occur if a uniform minimum BCR were applied in HERS across all four 5-year funding periods. The benefit-cost cutoff points were selected to coordinate with the total 20-year spending for each of the baseline analyses. At higher spending levels, the existence of the backlog of cost-beneficial investments would cause a higher percentage of spending to occur in the first 5-year period through 2015. This effect is less pronounced at lower levels of investment because some potential projects included in the estimated backlog would have a BCR below the cutoff point associated with that level of spending, and would thus be deferred for consideration in later funding periods. The percentage of total HERS-modeled, BCR-driven spending occurring in the first 5 years ranged from 29.5 percent for the lowest spending level analyzed to 41.2 percent for the highest level analyzed.

Impacts of Alternative Investment Patterns

An obvious difference among the three alternative investment patterns is that the higher the level of investment within the first 5-year analysis period, the better the level of performance achieved by 2015. At levels of HERS-modeled investment above $56.4 billion per year, the flat spending approach invests more in the first 5 years, resulting in lower IRI and average delay in 2015 than under the ramped spending approach; the reverse is true at funding levels less than $56.4 billion. The BCR-driven approach invests more in the first 5 years for all but the lowest average annual investment level presented of $43.2 billion per year; thus, at the higher investment levels, the BCR-driven approach achieves more IRI and delay reduction by 2015.

The more significant results pertain to system performance in 2030. In terms of average IRI, the flat spending approach and the BCR-driven approach yield results that are equal to or slightly inferior to those assuming ramped spending. For example, at an average annual investment level of $43.2 billion, average IRI would remain unchanged under the ramped spending approach or the BCR-driven approach in 2030 relative to 2010, but would increase by 0.4 percent under the flat spending approach.

The flat spending alternative achieves the largest reduction in average delay per VMT in 2030 relative to the baseline ramped spending approach only for HERS investment levels below the base-year level of $56.4 billion; the BCR-driven alternative produces average delay results equal or slightly inferior to the other two approaches at all levels of investment. For example, at an average annual investment level of $60.9 billion, average delay would remain unchanged under the ramped spending approach, but would increase by 0.1 percent under the flat funding alternative and by 0.4 percent under the BCR-driven funding alternative.

The significance of these 2030 results is that, although the ramped funding approach is often marginally superior to the two alternatives presented, it is ultimately the amount of funding invested over 20 years that has the most impact on system performance rather than the timing of that investment. Based on this analysis, the main advantage to front-loading highway investment is not in reducing 20-year investment

needs; instead, the advantage is the years of additional benefits that highway users would accrue over time if system conditions and performance were improved earlier in the 20-year period.

Alternative Timing of Investment in NBIAS

Exhibit 9-7 identifies the impacts of alternative investment timing on the average bridge sufficiency rating using four investment levels selected from those presented in Chapter 7. (See Chapter 7 for additional discussion of the sufficiency rating.) One of these investment levels matches the 2010 spending level of $17.1 billion on types of investments modeled in NBIAS, one corresponds to a higher level of investment of $20.2 billion annually (representing the NBIAS-derived component of the **Improve Conditions and Performance** scenario presented in Chapter 8), and two lower investment average annual levels of $14.3 billion and $12.2 billion (representing the NBIAS-derived component of the **Maintain Conditions and Performance** scenario presented in Chapter 8).

Exhibit 9-7 Distribution of Spending Among 5-Year Periods in NBIAS and Projected Impacts on the Average Bridge Sufficiency Rating, for Alternative Approaches to Investment Timing

Average Annual NBIAS-Modeled Capital Investment (Billions of 2010 Dollars)	Percentage of NBIAS-Modeled Spending Occurring in Each 5-Year Period											
	Baseline				Alternatives							
	Ramped Spending				Flat Spending				BCR-Driven Spending*			
	2011 to 2015	2016 to 2020	2021 to 2025	2026 to 2030	2011 to 2015	2016 to 2020	2021 to 2025	2026 to 2030	2011 to 2015	2016 to 2020	2021 to 2025	2026 to 2030
$20.2	22.2%	24.0%	25.9%	28.0%	25.0%	25.0%	25.0%	25.0%	38.9%	21.4%	20.7%	19.0%
$17.1	**25.0%**	**25.0%**	**25.0%**	**25.0%**	**25.0%**	**25.0%**	**25.0%**	**25.0%**	37.3%	22.8%	20.9%	19.1%
$14.3	28.3%	26.0%	23.8%	21.9%	25.0%	25.0%	25.0%	25.0%	34.5%	24.4%	21.3%	19.7%
$12.2	31.7%	26.7%	22.6%	19.0%	25.0%	25.0%	25.0%	25.0%	31.6%	23.5%	24.6%	20.3%

Average Annual NBIAS-Modeled Capital Investment (Billions of 2010 Dollars)	Projected Average Bridge Sufficiency Rating											
	Baseline				Alternatives							
	Ramped Spending, Percent Change as of:				Flat Spending, Percent Change as of:				BCR-Driven Spending* Percent Change as of:			
	2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
$20.2	82.8	83.9	84.6	84.6	83.4	84.4	84.5	84.3	85.3	84.6	84.1	83.9
$17.1	82.5	83.2	83.9	84.1	82.5	83.2	83.9	84.1	84.3	83.9	83.6	83.4
$14.3	82.3	82.5	82.9	83.2	81.5	81.8	82.7	83.5	83.2	82.9	82.8	82.9
$12.2	82.0	81.8	81.7	**81.7**	80.6	80.3	80.9	82.2	82.1	81.5	81.8	82.1

** Each percentage distribution shown corresponds to a NBIAS analysis assuming investment up to a minimum benefit-cost ratio cutoff point (not shown) which was set at a level such that 20-year spending would be consistent with the average annual spending level shown.*

Source: National Bridge Investment Analysis System.

Similar to the HERS results presented earlier, the projected average bridge sufficiency rating in 2015 is driven by the amount of NBIAS investment during the first 5-year period. Unlike the HERS results presented earlier, NBIAS does not find the maximum level of cost-beneficial investment to be lower under the two alternatives than under the baseline ramped spending approach; in all three cases, NBIAS identified 20 years of cost-beneficial investment corresponding to an average annual investment level of $20.2 billion.

At an average annual investment level of $20.2 billion, NBIAS projects that the highest average bridge sufficiency rating in 2030 would be achieved under the baseline ramped spending approach at 84.6 (on a scale of 0 to 100), compared to 84.3 assuming ramped spending and 83.9 for the BCR-driven spending

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alternative. However, at an average annual investment level of $12.2 billion, NBIAS projects that the average bridge sufficiency rating in 2030 would match the 2010 level of 81.7 assuming the baseline ramped funding approach, which is lower than the 82.2 and 82.1 average sufficiency ratings projected for the flat spending and BCR-driven spending alternatives, respectively.

The BCR-driven spending approach is intended to better align annual capital spending to annual needs. This approach has a benefit in terms of reducing ongoing maintenance costs; however, front-loading capital investment in this manner tends to exacerbate the concentration of future bridge needs by putting a larger number of bridges on the same repair and rehabilitation cycle. The imposition of an annual spending constraint in the baseline ramped spending analyses tends to stretch out bridge work across a longer period, so that subsequent repair and rehabilitation cycles would be more spread out.

Transit Supplemental Scenario Analysis

This section is intended to provide the reader with a deeper understanding of the assumptions behind the scenarios presented in Chapters 7 and 8 and also of the real-world issues that impact transit operators' ability to address their outstanding capital needs. Specifically, this section includes discussion of the following topics:

- Asset condition forecasts under four scenarios: (1) Sustain 2010 Spending, (2) State of Good Repair (SGR) benchmark, (3) Low Growth, and (4) High Growth
- A comparison of 2010 to 2013 TERM results
- A comparison of recent historic passenger miles traveled (PMT) growth rates with the growth projections of the Nation's Metropolitan Planning Organizations (MPOs)
- An assessment of the impact of purchasing hybrid vehicles to the backlog estimate
- The forecast of purchased transit vehicles, route miles, and stations under the **High Growth** and **Low Growth** scenarios.

Asset Conditions Forecasts and Expected Useful Service Life Consumed for All Transit Assets Under Four Scenarios

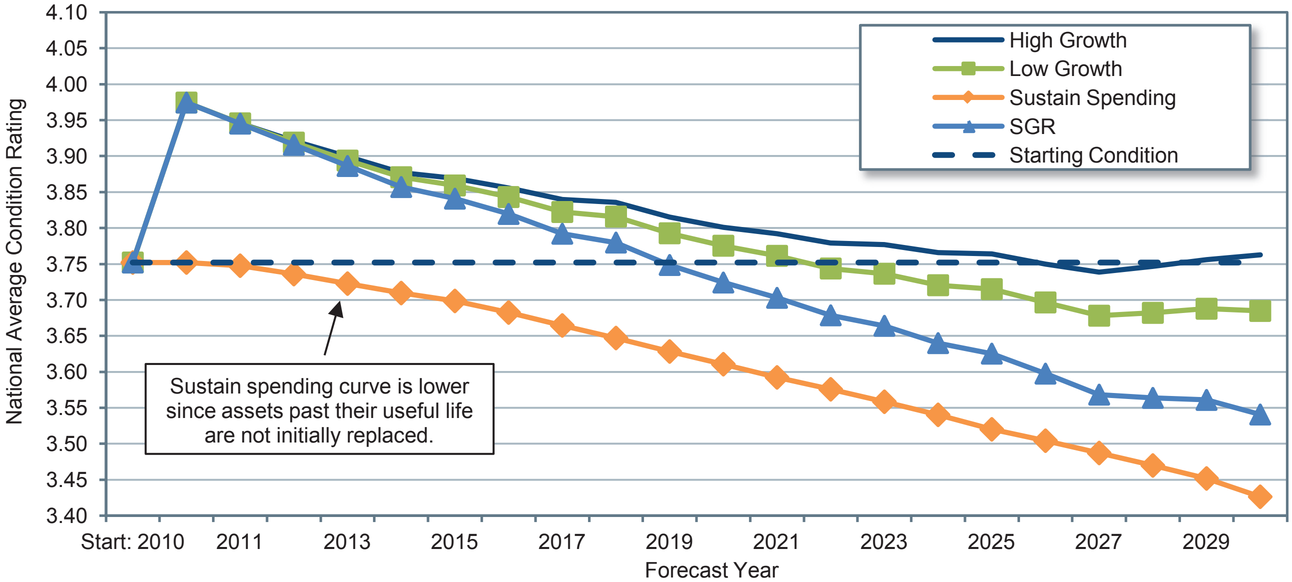
As in the 2010 edition, this edition of the C&P report uses four condition projection scenarios (i.e., **SGR benchmark**, **Sustain 2010 Spending**, **Low Growth**, and **High Growth** scenarios) to better understand which conditions outcome is desirable or even sensible. For example, are current asset conditions at an acceptable level or are they too low (or too high) for individual asset types?

To help answer this question, consider *Exhibit 9-8*, which presents the condition projections for each of the four scenarios. Note that these projections predict the condition of all transit assets in service each year of the 20-year analysis period, including transit assets that exist today and any investments in expansion assets by these scenarios. The **Sustain 2010 Spending**, **Low Growth**, and **High Growth** scenarios each make investments in expansion assets while the **SGR benchmark** scenario only reinvests in existing assets. Note that the estimated current average condition of the Nation's transit assets is 3.75. As discussed in Chapter 8, expenditures under the financially constrained **Sustain 2010 Spending** scenario are not sufficient to address replacement needs as they arise, leading to a predicted increase in the investment backlog. This increasing backlog is a key driver in the decline in average transit asset conditions as shown for this scenario in *Exhibit 9-8*.

In contrast to the **Sustain 2010 Spending** scenario, the **SGR benchmark** scenario is financially unconstrained and considers the level of investment required to both eliminate the current investment backlog and to address all ongoing reinvestment needs as they arise such that all assets remain in an SGR (i.e., a condition of 2.5 or higher). Despite adopting the objective of maintaining all assets in an SGR throughout the forecast period, average conditions under the **SGR benchmark** scenario ultimately decline to levels well below the current average condition value of 3.75.

This result, although counterintuitive, is explained by a high proportion of long-lived assets (e.g., guideway structures, facilities, and stations) that currently have fairly high average condition ratings and a significant amount of useful life remaining, as shown in *Exhibit 9-9.* The exhibit shows the share of all transit assets (equal to approximately $658 billion in 2010) as a function of their useful life consumed. The spike in

Exhibit 9-8 Asset Condition Forecast for All Existing and Expansion Transit Assets

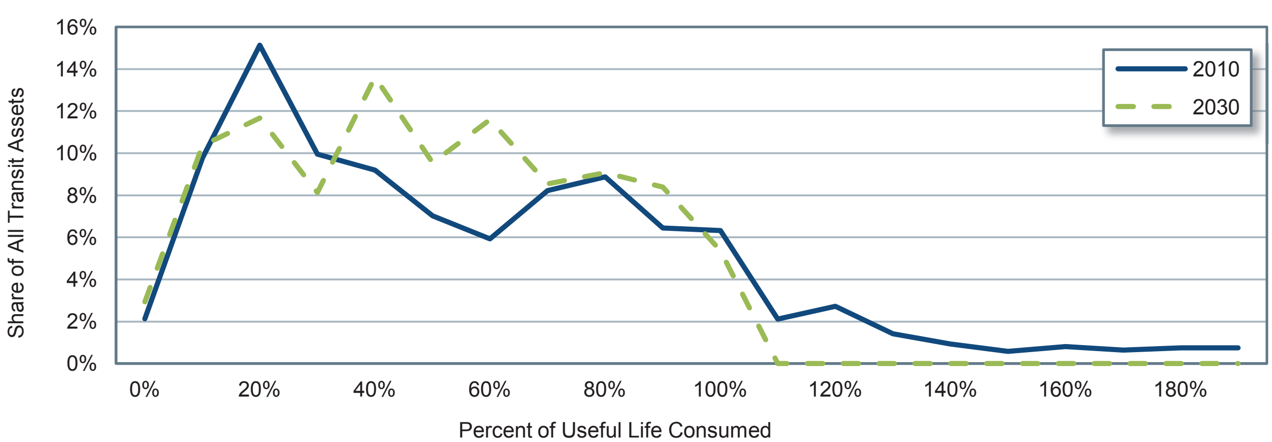


Source: Transit Economic Requirements Model.

Exhibit 9-9 at the point where only 20 percent of useful life has been consumed is driven in part by ongoing expansion investments. Elimination of the current SGR backlog removes a significant number of over-age assets from service (resulting in an initial jump in asset conditions), but the ongoing aging of the longer-lived assets will ultimately draw the average asset conditions down to a long-term condition level that is consistent with the objective of SGR (and hence sustainable) but ultimately measurably below current average aggregate conditions.

If the **SGR benchmark** scenario represents a reasonable long-term investment strategy (i.e., replacing assets close to the end of their useful life which results in a long-term decline in average conditions), then investing under the **Sustain 2010 Spending** scenario implies an investment strategy of replacing assets at later ages, in worse conditions, and potentially after the end of their useful life, as shown in *Exhibit 9-10*. Expenditures on asset reinvestment for the **Sustain 2010 Spending** scenario are insufficient to address ongoing reinvestment needs, leading to an increase in the size of the backlog. Note that the forecast for 2030 for the **Sustain 2010**

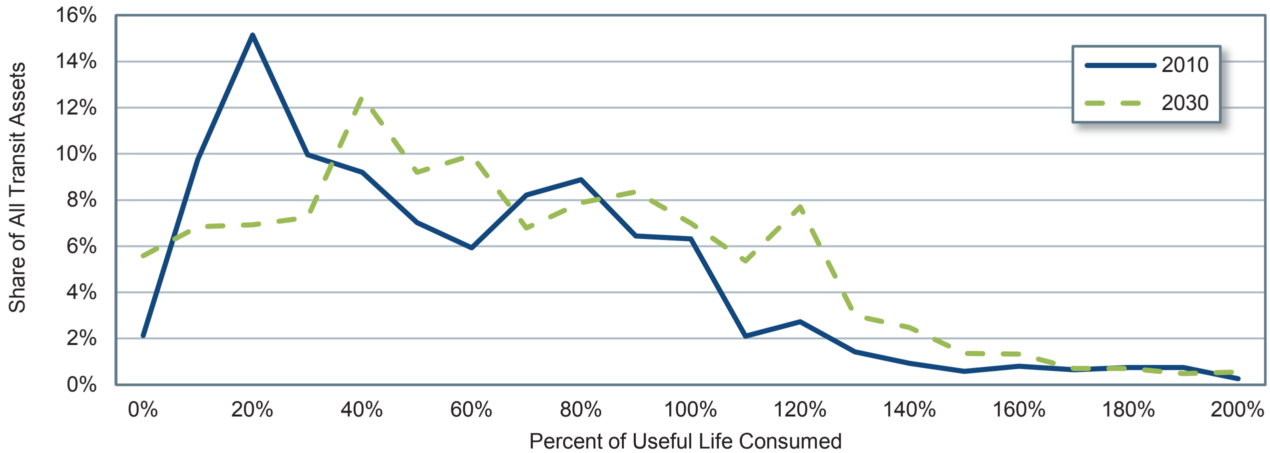
Exhibit 9-9 SGR Baseline Scenario: Asset Percent of Useful Life Consumed



Source: Transit Economic Requirements Model.

Spending scenario in *Exhibit 9-10* indicates that assets under this scenario will be closer to or beyond the end of their useful life when compared with the other scenarios; this difference reflects a larger portion of the national transit assets still in use after the end of their useful lives.

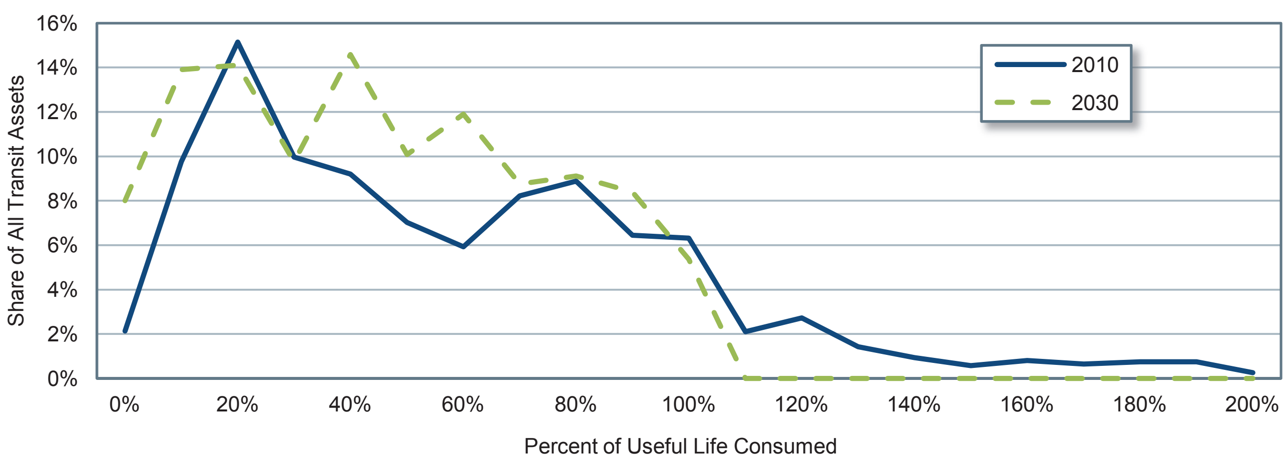
Exhibit 9-10 Sustain 2010 Spending Scenario: Asset Percent of Useful Life Consumed



Source: Transit Economic Requirements Model.

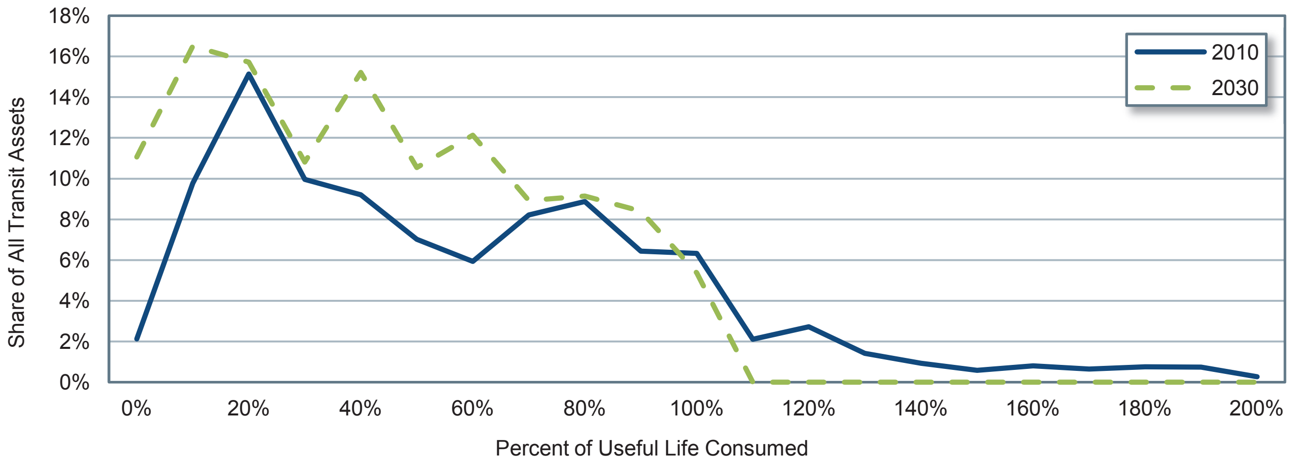
To underscore these findings, note that the **Low Growth** scenario and the **High Growth** scenario include unconstrained investments in both asset replacements and asset expansions. Hence, not only are older assets replaced as needed with an aggressive reinvestment rate, but new expansion assets are also continually added to support ongoing growth in travel demand. While initially insufficient to fully arrest the decline in average conditions, the impact of these expansion investments would ultimately reverse the downward decline in average asset conditions in the final years of the 20-year projections. This would also result in a higher proportion of long-lived assets with a larger amount of useful life remaining in 2030 than in 2010 as illustrated in *Exhibit 9-11* and *Exhibit 9-12,* respectively. Furthermore, the **High Growth** scenario (*Exhibit 9-12*) adds newer expansion assets at a higher rate than does the **Low Growth** scenario (*Exhibit 9-11*), ultimately yielding higher average condition values for that scenario (and average condition values that exceed the current average of 3.75 throughout the entire forecast period).

Exhibit 9-11 Low Growth Scenario: Asset Percent of Useful Life Consumed



Source: Transit Economic Requirements Model.

Exhibit 9-12 **High Growth Scenario: Asset Percent of Useful Life Consumed**



Source: Transit Economic Requirements Model.

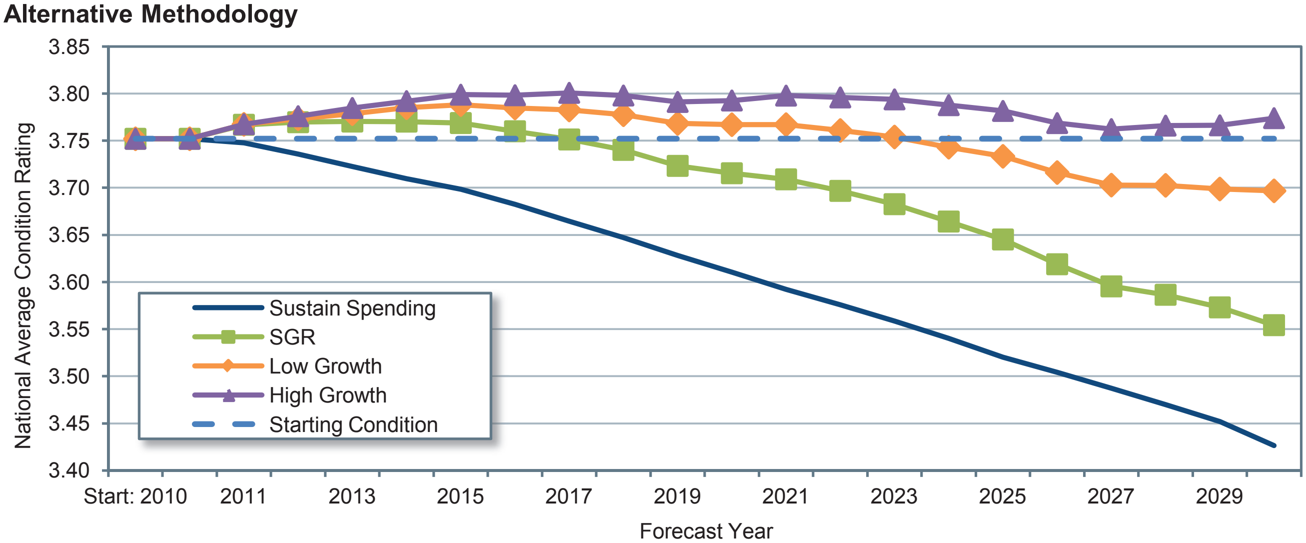
Alternative Methodology

When we consider current transit investment practices, the level of investment needed to eliminate the SGR backlog in 1 year is unfeasible. So the **SGR benchmark**, **Low Growth**, and **High Growth** scenarios' financially unconstrained assumptions (e.g., spending of unlimited transit investment funds each year) is unrealistic. As indicated in *Exhibit 9-8*, the elimination of the backlog in the first year and the resulting jump in asset conditions in year 1 can be attributed to this unconstrained assumption.

An alternative, more feasible methodology is to have the **SGR benchmark**, **Low Growth**, and **High Growth** scenarios use a financially constrained reinvestment rate to eliminate the SGR backlog by year 20 while maintaining the collective national transit assets at a condition rating of 2.5 or higher. Analysis has determined that investing $17.5 billion annually would achieve this objective of eliminating the backlog in 20 years.

Exhibit 9-13 presents the condition projections for each of the four scenarios using this alternative methodology. However, the **SGR benchmark**, **Low Growth**, and **High Growth** scenarios are financially constrained so the investment strategies result in replacing assets at later ages, in worse conditions, and potentially after the end of their useful lives.

Exhibit 9-13 **Asset Condition Forecast for All Existing and Expansion Transit Assets Under Alternative Methodology**



Source: Transit Economic Requirements Model.

Comparison of 2010 to 2013 TERM Results

The backlog and investment needs estimated by TERM differ between the 2010 and 2013 C&P Reports. This section compares the TERM results between these two reports and explains why they differ.

The estimated backlog in the 2013 C&P Report increased from $77.7 billion (as reported in the 2010 C&P Report) to $85.9 billion, representing an increase of more than 10 percent. There are three primary reasons for the increase in the backlog:

- **Additional needs:** The value of the backlog is strongly correlated to the age of the inventory of assets. Certain assets that were nearing the condition threshold of 2.5 in 2008 continued to age and degrade until 2010. As the predicted condition of these assets moved from better than 2.5 to worse than 2.5 during this period, the cost of replacing them was added to the backlog calculation. The backlog increased by $9 billion for this reason between the 2010 and the 2013 C&P Report.
- **Inflation:** Using published construction inflation factors, the backlog was escalated from 2008 to 2010 dollars. The impact of inflation on the backlog between the 2010 and 2013 C&P Reports is $3.6 billion.
- **Changed Asset Inventory:** The asset inventory used in the TERM simulation consists of nearly 84,000 asset records for almost 2,400 transit agencies. For each edition of the C&P report, the Federal Transit Administration (FTA) collects new asset data from select agencies. In general, agencies continue to improve the defensibility and accuracy of their inventory data. As a result, FTA expects some change to reflect the improved data. For the 2013 C&P Report, the impact of improved data resulted in a net decrease of approximately $4.4 billion.

Exhibit 9-14 Causes of the Increase in the Backlog between the 2010 C&P Report and the 2013 C&P Report

	Billion $
SGR Backlog as reported in the 2010 C&P report	**$77.7**
Impact of two additional years of needs	**+9.0**
Impact of inflation	**+3.6**
Impact from the change in the asset inventory	**-4.4**
SGR Backlog as reported in the 2013 C&P report	**$85.9**

Source: Transit Economic Requirements Model.

Exhibit 9-14 provides a summary of these three adjustments. Note that the SGR backlog of $77.7 billion dollars comes from *Exhibit 8-30* in the 2008 C&P Report.

Nonrail investment projections decreased in this 2013 C&P Report relative to the 2010 C&P Report for all scenarios, as presented in *Exhibit 9-15*, while rail investments decreased in this report relative to the previous report only for the **High Growth** scenario. This is because the high growth rate in this 2013 C&P Report is lower than the high growth rate in the 2010 C&P Report.

The high growth rate is projected using 10- or 15-year historical ridership growth trends. The 2010 C&P Report used a 10-year trend (1999 to 2008), which gave a high growth rate of 2.8 percent. The 10-year trend for the 2013 C&P Report (2001 to 2010) included the effects of the recession and, thus, was not

Exhibit 9-15 Comparison of Projected Investment Needs for 2010 and 2013 C&P Report Investment Scenarios

	Investment Projection (Billions of 2010 Dollars)					
	Nonrail		Rail		Total	
Scenario	2010 C&P Report	2013 C&P Report	2010 C&P Report	2013 C&P Report	2010 C&P Report	2013 C&P Report
Sustain 2010 Spending	$6.4	$5.8	$10.7	$10.7	**$17.1**	**$16.5**
SGR Benchmark	$7.5	$6.7	$11.6	$11.7	**$19.1**	**$18.5**
Low Growth	$8.4	$7.8	$13.6	$14.2	**$22.1**	**$22.0**
High Growth	$10.0	$9.2	$16.0	$15.3	**$26.0**	**$24.5**

Source: Transit Economic Requirements Model.

much higher than the low growth rate of 1.4 percent. Accordingly, a 15-year historical time horizon was used to calculate the high growth rate for the 2013 C&P Report, which resulted in a growth rate of 2.2 percent. The low growth rate is the MPO-projected ridership growth rate and is roughly the same for both reports.

Comparison of Passenger Miles Traveled (PMT) Growth Rates

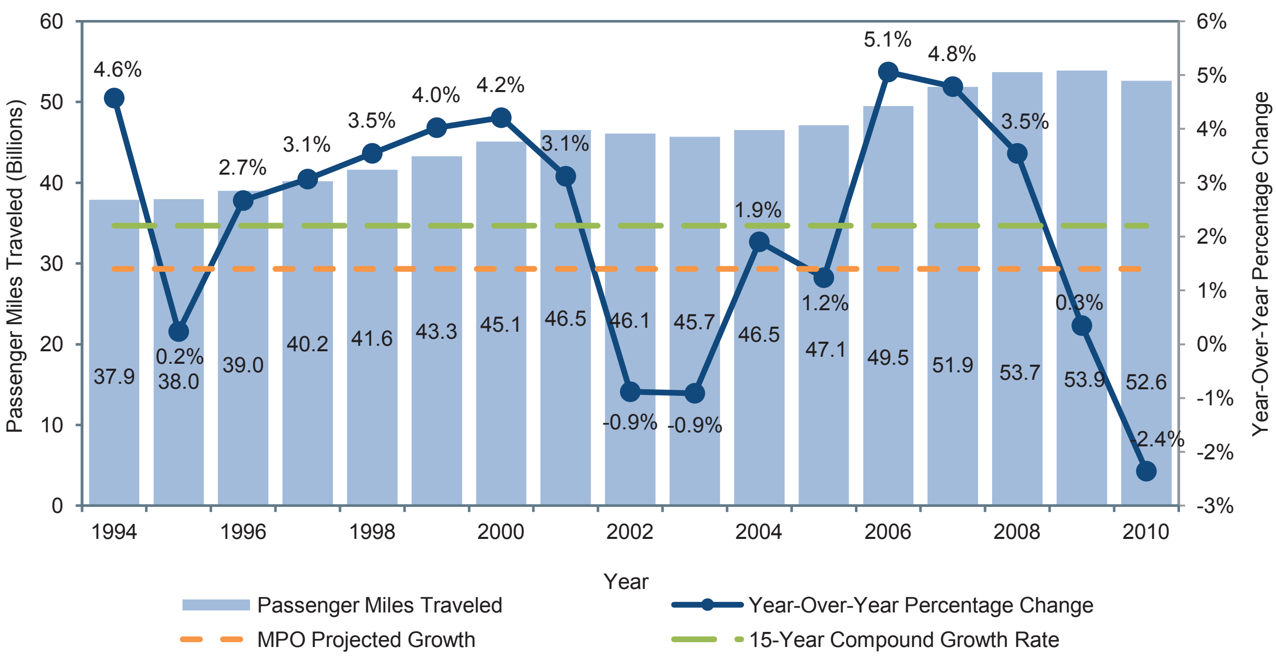
The **Low Growth** and **High Growth** scenarios presented in Chapter 8 assessed transit expansion investment needs assuming two differing rates of growth in transit PMT. Specifically, the **Low Growth** scenario assumed urbanized-area (UZA)–specific rates of PMT growth as projected by the Nation's MPOs. The **High Growth** scenario assumed the UZA-specific average annual compound rates experienced over the most recent 15-year period. The objective of this discussion is to put into perspective these two differing growth rates.

In general, the MPO projections are believed to provide a lower range for PMT growth because these projections are financially constrained (i.e., the assumed rate of transit and highway network expansion is constrained to what is feasible given expected future funding capacity and long-term expansion plans). Hence, while the **Low Growth** scenario is intended to represent unconstrained transit investment needs given a projected rate of increase in PMT, the MPO PMT growth rates underlying this scenario are financially constrained, thus imposing an implicit financial constraint on this scenario. The UZA PMT projections used for the **Low Growth** scenario were provided by a sample of MPOs; this sample was dominated by the Nation's largest UZAs but also included a mix of small- and medium-sized metropolitan areas from around the Nation. When weighted to account for differences in current annual PMT, this sample yields a weighted national average PMT growth rate of 1.3 percent.

MPO Growth Compared to Historical Growth for All Urbanized and Rural Areas

As shown in *Exhibit 9-16*, the historical rates of PMT growth experienced over the past 16 years have typically been in excess of the MPO-projected growth rates. During the period from 1994 through 2010

Exhibit 9-16 Passenger Miles Traveled, All Urbanized and Rural Areas



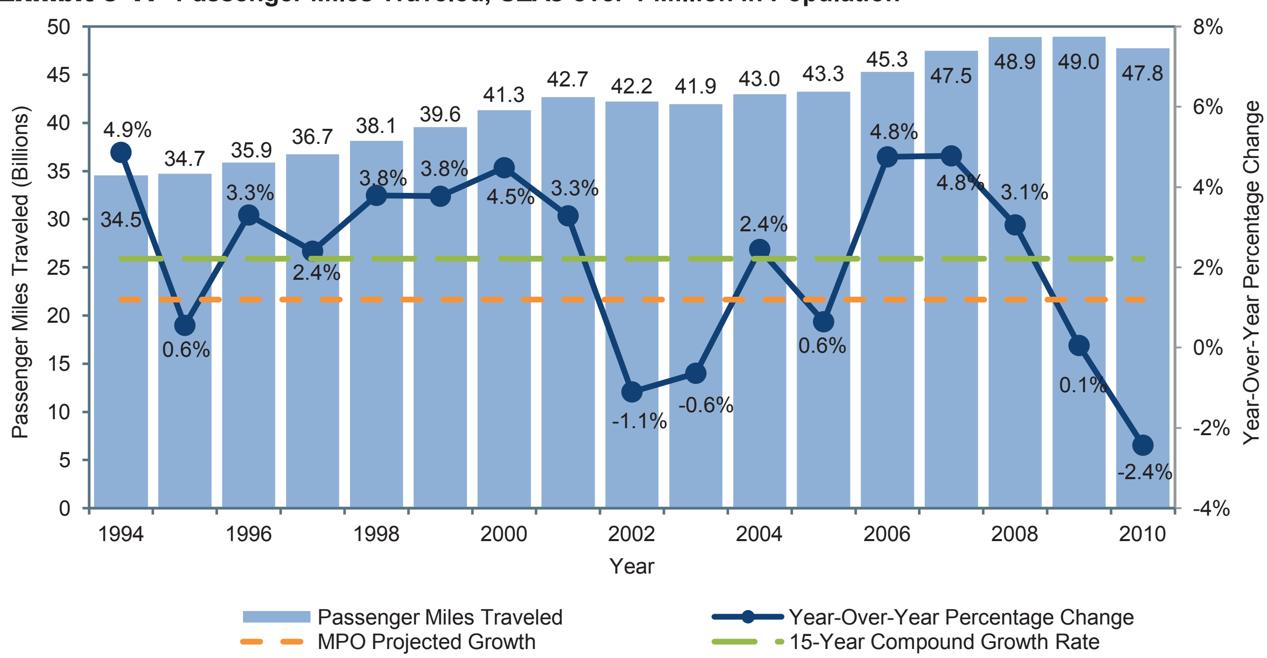
Source: NTD and MPO estimates.

presented in *Exhibit 9-16*, the compound annual growth rate averaged roughly 2.1 percent rather than the 1.3-percent growth rate projected by MPOs for the upcoming 20- to 30-year period. The average compound annual growth rate of 2.1 percent closely resembles the 2.0 percent high growth rate. Given the significant difference in these two rates (and the relatively high rate of historic PMT growth as compared to other additional measures, such as urban area population growth), the historical rate of PMT was identified as a reasonable input value for the **High Growth** (or higher-growth) scenario. There is a significant drop in year-over-year percentage change in 2009 and 2010 PMT that is mostly due to the decrease in PMT for UZAs over 1 million in population.

UZAs Over 1 Million in Population

As shown in *Exhibit 9-17*, the difference between the MPO-projected growth rate and the recent historical PMT growth rate remains unchanged when limited to UZAs with populations greater than 1 million. For these larger UZAs, the compound average annual growth rate again averaged roughly 2.2 percent during the period from 1994 through 2010 as compared with the 1.2-percent growth rate projected by MPOs for the up-coming 20- to 30-year period.

Exhibit 9-17 Passenger Miles Traveled, UZAs over 1 Million in Population

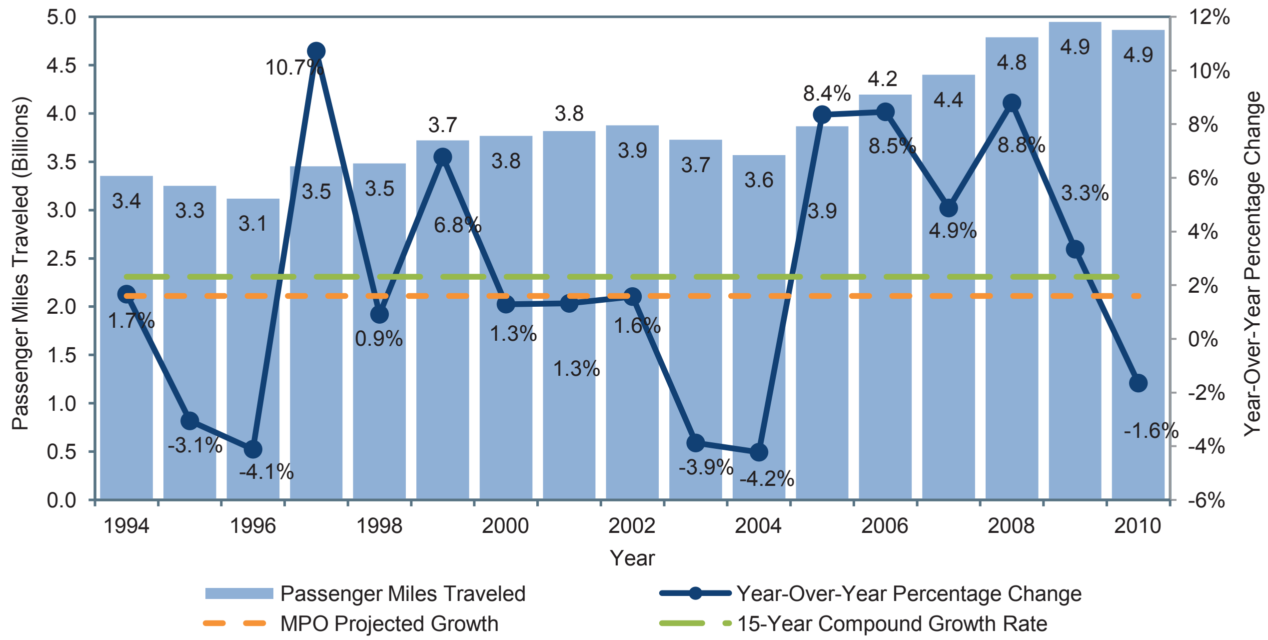


Source: NTD and MPO estimates.

UZAs Under 1 Million in Population and Rural Areas

Finally, as shown in *Exhibit 9-18*, there is significantly less difference between the MPO-projected and recent annual average historical PMT growth rates when the analysis is limited to urbanized areas with populations less than 1 million and rural areas. For UZAs under 1 million in population, the compound average annual growth rate averaged roughly 2.3 percent during the period from 1994 through 2010, which is close to the 2.2-percent growth rate projected by MPOs for this group. There are two significant differences to note here with the findings for the larger UZAs. First, the MPO-projected rate of increase for UZAs under 1 million in population is roughly 64 percent higher than for UZAs over 1 million in population. This difference is partly accounted for by (1) the higher rates of population growth in many of these smaller UZAs (particularly in the south and in the west) and (2) proposed light and commuter rail investments in some UZAs in this group. Second, the year-to-year variance in the actual growth rates is roughly double that

Exhibit 9-18 Passenger Miles Traveled, UZAs Under 1 Million in Population



Source: NTD and MPO estimates.

experienced by UZAs over 1 million in populations. The percent change in annual passenger miles traveled varies with a low of -4.2 percent to a high of 10.7 percent over the 17-year period. Given this variability in growth rates, it is important to have alternative growth rates (i.e., **Low Growth** and **High Growth** scenarios) for projection purposes.

Impact of New Technologies on Transit Investment Needs

The investment needs scenarios presented in Chapter 8 implicitly assume that all replacement and expansion assets will utilize the same technologies as are currently in use today (i.e., all asset replacement and expansion investments are "in kind'). However, as with most other industries, the existing stock of assets used to support transit service is subject to ongoing technological change and improvement and this change tends to result in increased investment costs (including future replacement needs). While many of these improvements are standardized and hence embedded in the asset (i.e., the transit operator has little or no control over this change), there are numerous instances where transit operators have intentionally selected technology options that can be significantly more costly than pre-existing assets of the same type. A key example here is the frequent decision to replace diesel motor buses with compressed natural gas (CNG) or hybrid buses. While these options offer clear environmental benefits (and CNG may also result in decreases in operating costs), acquisition costs for these vehicle types are 20 to 60 percent higher than diesel. This increase in costs generally increases current and long-term reinvestment needs and, in a budget-constrained environment, increases the expected future size of the investment backlog. This increase may be offset by lower operating costs from more reliable operation, longer useful lives, and improved fuel efficiency, but this possible offset is not captured in this assessment of capital needs. Again, the impact of these technology-driven increases in needs is not included in the needs estimates presented in Chapters 7 and 8 of this report.

In addition to improvements in pre-existing asset types, transit operators periodically expand their existing asset stock to introduce new asset types that take advantage of technological innovations. Good examples include investments in intelligent transportation system technologies such as real-time passenger information systems and automated dispatch systems, assets and technologies that are common today but that were

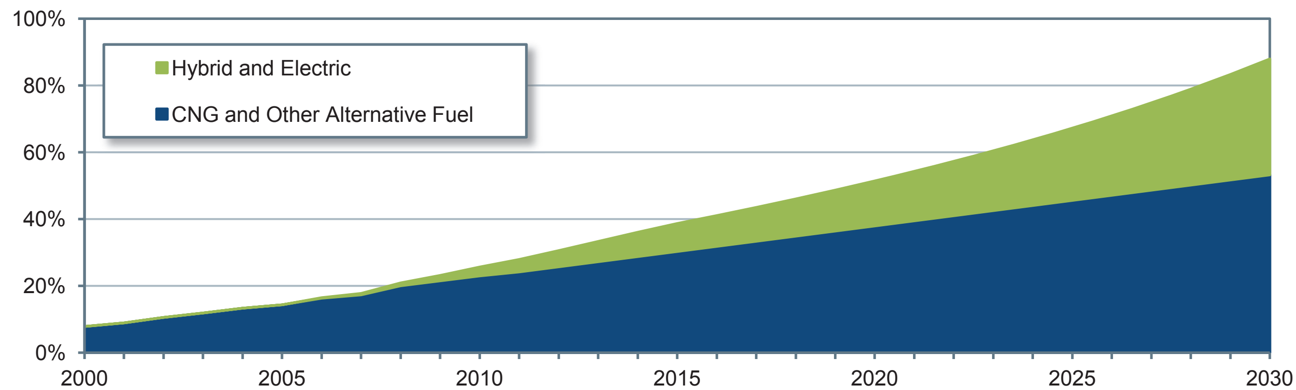
not available 15 to 20 years ago. These improvements typically yield improvements in service quality and efficiency, but they also tend to yield increases in asset acquisition, maintenance, and replacement costs, resulting in an overall increase in reinvestment costs as well as the expected future size of the SGR backlog.

Impact of Compressed Natural Gas and Hybrid Buses on Future Needs

To provide a better sense of the impact of new technology adoption on long-term needs, the analysis below presents estimates of the long-term cost of the shift from diesel to compressed natural gas (CNG) and hybrid buses. It is important to emphasize that this analysis is only intended to provide a sense of the significance of this impact on long-term capital needs (including the possible consequences of not capturing this impact in TERM's needs estimates). This is not an assessment of the full range of operational, environmental, or other potential costs and benefits arising from this shift and, hence, is not an evaluation of the decision to invest in any specific technology.

Exhibit 9-19 below presents historical (2000 to 2010) and forecast (2011 to 2030) estimates of the share of transit buses that rely on CNG and other alternative fuels vehicles and on hybrid power sources. The forecast estimates assume the current trend rate of increase in alternative and hybrid vehicle shares as observed over the period 2005 to 2010. Based on this projection, the share of vehicles powered by alternative fuels is estimated to increase from 23 percent in 2010 to 53 percent in 2030. During the same period, the share of hybrid buses is estimated to increase from 3 percent to 35 percent. This results in diesel shares declining from roughly 74 percent today to roughly 12 percent by 2030.

Exhibit 9-19 Hybrid and Alternative Fuel Vehicles: Share of Total Bus Fleet, 2000–2030



Source: Transit Economic Requirements Model.

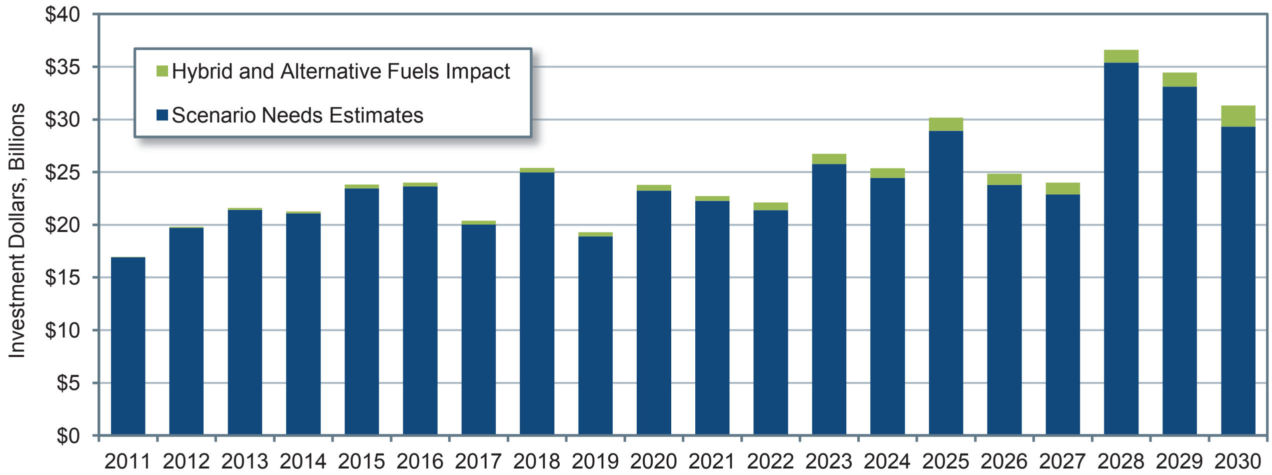
Impact on Costs

Based on FTA analysis, the average unit cost of an alternative fuels bus is 15.5 percent higher than that of a standard diesel bus of the same size. Similarly, hybrid buses cost roughly 65.9 percent more than standard diesel buses of the same size. When combined with the current and projected mix of bus vehicle types presented above in *Exhibit 9-19*, these cost assumptions yield an estimated increase in average bus vehicle capital costs of 25.7 percent over the period 2010 to 2030 (using the mix of bus types from 2010 as the base of comparison). (It is important to note here that this cost increase represents a shift in the mix of bus types purchased and not the impact of underlying inflation, which will impact all vehicle types, including diesel, alternative fuels, and hybrid.) Reductions in operating costs due to the new technology are not shown in this analysis of capital needs but are presumably part of the motivation for agencies that purchase these vehicles.

Impact on Needs

What, then, is the impact of this cost increase on long-term transit capital needs? *Exhibit 9-20* presents the impact of this potential cost increase on annual transit needs as estimated for the **Low Growth** scenario

Exhibit 9-20 **Impact of Shift to Vehicles Using Hybrid and Alternative Fuels on Investment Needs: Low Growth Scenario**



Source: Transit Economic Requirements Model.

presented in Chapter 8. For this scenario, the cost impact is negligible in the early years of the projection period but grows over time as the proportion of buses using alternative fuel and hybrid power increases (note that the investment backlog is not included in this depiction). The impact on total investment needs for all Chapter 9 investment scenarios (**SGR baseline**, **Low Growth**, and **High Growth**) is presented in dollar and percentage terms in *Exhibit 9-21*. Note that the shift to alternative fuels and hybrid buses is estimated to increase average annual replacement needs by $0.5 to $0.8 billion, yielding a 2.5- to 3.5-percent increase in investment needs. To help place these estimated amounts in perspective, it is helpful to note that (1) the shift from diesel to alternative fuels and hybrid buses is only one of a number of technology changes that may impact long-term transit reinvestment needs, but (2) reinvestment in transit buses likely represents the largest share of transit needs subject to this type of significant technological change. Hence, the impact of all new technology adoptions (not accounted for in the Chapter 8 scenarios and including but not limited to new bus propulsion systems) may add on the order of 5 to 10 percent to long-term transit capital needs.

Exhibit 9-21 **Impact of Shift from Diesel to Alternative Fuels and Hybrid Vehicles on Annual Investment Needs**

Measure	SGR Baseline	Low Growth	High Growth
Average Annual Needs	$0.47B	$0.67B	$0.83B
Percent Increase	2.50%	3.00%	3.50%

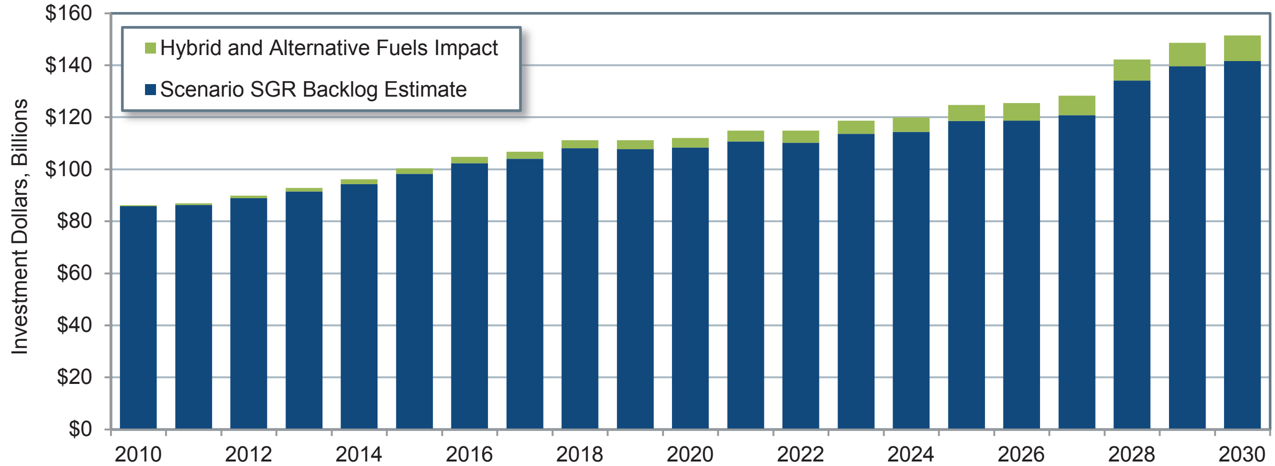
Source: Transit Economic Requirements Model.

Impact on Backlog

Finally, in addition to impacting unconstrained capital needs, the shift from diesel to hybrid and alternative-fuel vehicles can also have an impact on the size of the future backlog. For example, *Exhibit 9-22* shows the estimated impact of this shift on the SGR backlog as was estimated for the **Sustain 2010 Spending** scenario from Chapter 8. Under this scenario, long-term spending is capped at current levels such that any increase in costs over the analysis period must necessarily be added to the backlog. Moreover, given that buses' useful lives as estimated by TERM range from roughly 7 to 14 years, all existing and many expansion vehicles will need to be replaced over the 20-year analysis period, meaning that any increase in costs for this asset type will be added to the backlog over this period of analysis.

As with the analysis above, *Exhibit 9-22* suggests that the initial impact of the shift to hybrid and alternative-fuel vehicles is small but increases over time as these vehicle types make up an increasing share of the Nation's bus fleet. By 2030, this shift is estimated to increase the size of the backlog from $141.7 billion to $151.4 billion, an increase of $9.8 billion or 6.9 percent.

Exhibit 9-22 **Impact of Shift to Vehicles Using Hybrid and Alternative Fuels on Backlog Estimate: Sustain 2010 Spending Scenario**



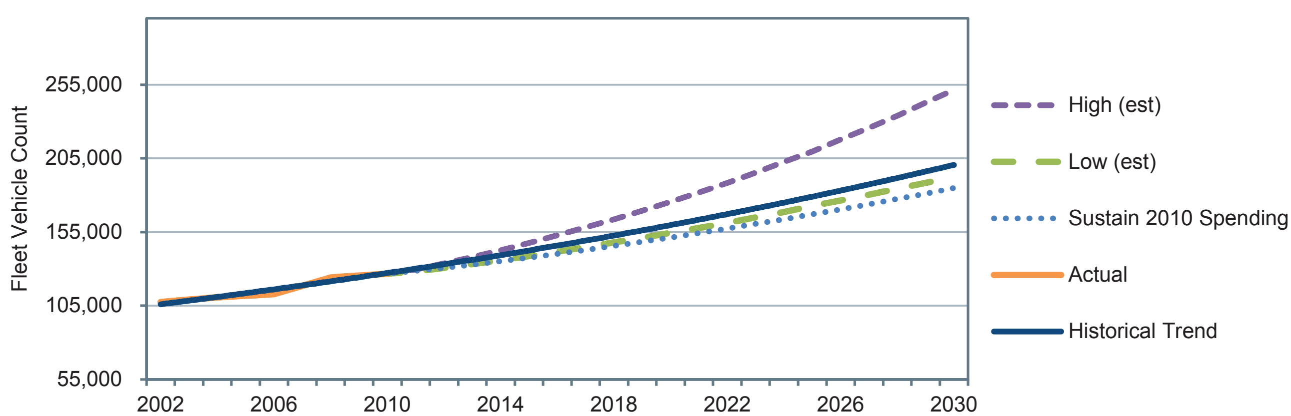
Source: Transit Economic Requirements Model.

Forecasted Expansion Investment

This section compares key characteristics of the national transit system in 2010 to their forecasted TERM results over the next 20 years for different scenarios. It also includes expansion projections of fleet size, guideway route miles, and stations broken down by scenario to better understand the expansion investments that TERM is making.

TERM's projections of fleet size are presented in *Exhibit 9-23*. The projections for the **Low Growth** and **High Growth** scenarios are higher than the projected **Sustain 2010 Spending** scenario in order to preserve existing transit assets at a condition rating of 2.5 or higher and expand transit service capacity to support differing levels of ridership growth while passing TERM's benefit-cost test. An exponential trend line based on historical data from 2002 to 2010 is extrapolated 20 years into the future also is shown in *Exhibit 9-23*. This extrapolated historical trend line falls between the low and high growth projections indicating that the **Low Growth** and **High Growth** scenario investments potentially could maintain current conditions.

Exhibit 9-23 **Projection of Fleet Size by Scenario**

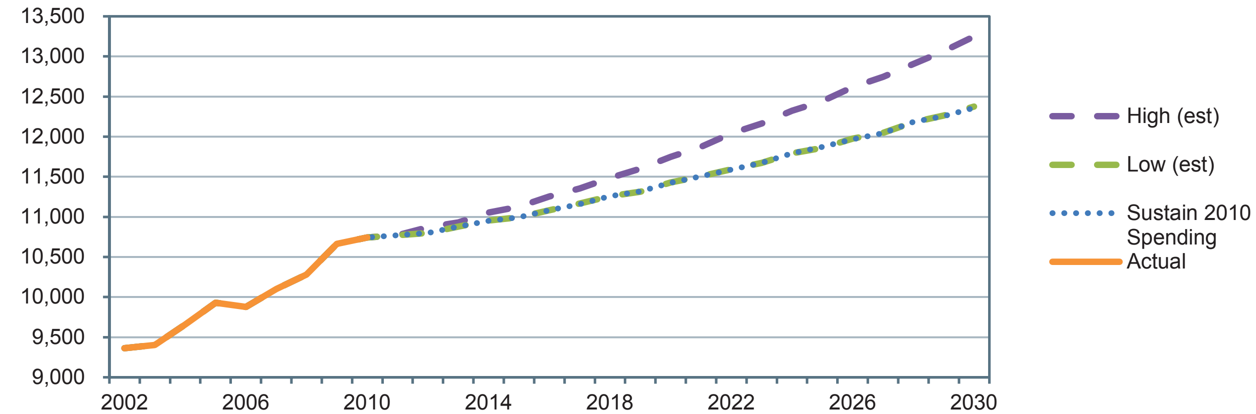


Note: Data through 2010 are actual; data after 2010 are estimated based on trends.

Source: Transit Economic Requirements Model.

In contrast, the projected guideway route miles for the **Sustain 2010 Spending**, **Low Growth**, and **High Growth** scenarios are less than the projected historical trend scenario as shown in *Exhibit 9-24*. (Note that TERM's projections of guideway route miles for the **Sustain 2010 Spending** and **Low Growth** scenarios are nearly identical.) Commuter rail has substantially more guideway route miles than heavy and light rail, making it very hard to accurately project total guideway route miles for all rail modes; therefore, the historical trend line is not provided.

Exhibit 9-24 Projection of Guideway Route Miles by Scenario

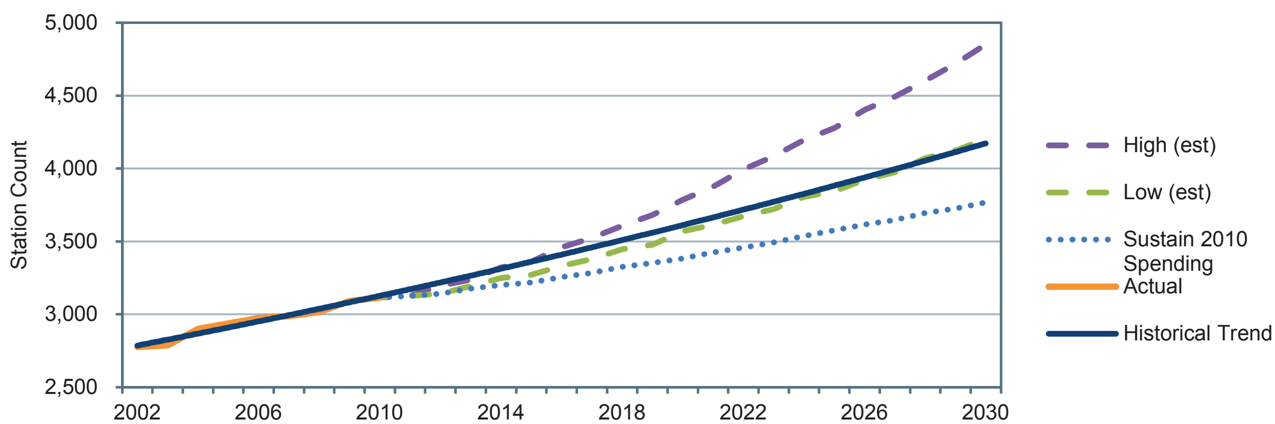


Note: Data through 2010 are actual; data after 2010 are estimated based on trends.

Source: Transit Economic Requirements Model.

TERM's expansion projections of stations by scenario needed to preserve existing transit assets at a condition rating of 2.5 or higher and expand transit service capacity to support differing levels of ridership growth (while passing TERM's benefit-cost test) are presented *Exhibit 9-25*, along with the historical trend. TERM's **Low Growth** estimates generally are in line with the historical trend, indicating that expansion projects of stations under the **Low Growth** scenario could maintain current transit conditions.

Exhibit 9-25 Projection of Stations by Scenario

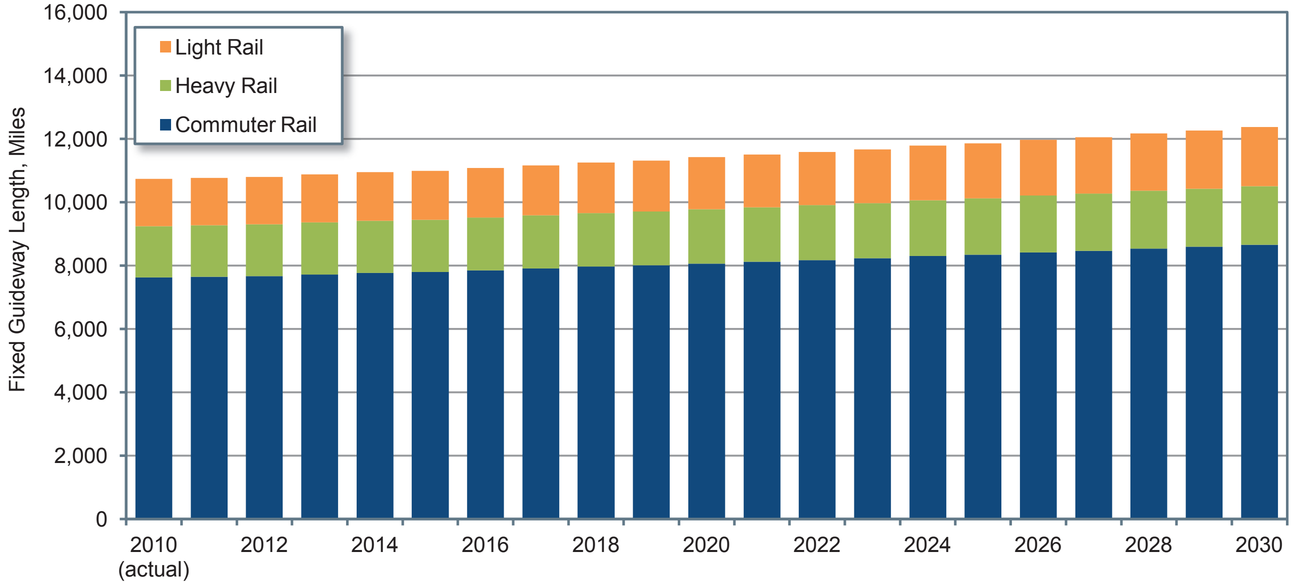


Note: Data through 2010 are actual; data after 2010 are estimated based on trends.

Source: Transit Economic Requirements Model.

For each of the various scenarios, TERM estimates future investment in fleet size, guideway route miles, and stations for each of the next 20 years. *Exhibit 9-26* presents TERM's projection for total fixed guideway route miles under a **Low Growth** scenario by rail mode. TERM projects different investment needs for each year that is added to the year 2010 actual total stock. Heavy rail's share of the projected annual fixed guideway route miles remains relatively constant over the 20-year period, while the amount of fixed guideway route miles increases slightly for light and commuter rail.

Exhibit 9-26 Stock of Fixed Guideway Miles by Year Under Low Growth Scenario, 2010–2030



Source: Transit Economic Requirements Model.

CHAPTER 10

Sensitivity Analysis

Highway Sensitivity Analysis

In any modeling effort, it is critical to evaluate the validity of the underlying assumptions and determine the degree to which projected outcomes could be affected by changes to these assumptions. This section demonstrates how the average annual highway investment requirements associated with the **Maintain Conditions and Performance** scenario and the **Improve Conditions and Performance** scenario presented in Chapter 8 would be affected by changes in some of the underlying assumptions in the Highway Economic Requirements System (HERS) and the National Bridge Investment Analysis System (NBIAS). To simplify the presentation of results, these sensitivity tests were applied only to the systemwide versions of these scenarios based on HPMS-derived future growth in vehicle miles traveled (VMT), rather than to the full range of subscenarios presented in Chapter 8.

This section begins with sensitivity tests on economic inputs to the models, varying the assumptions about the value that travelers attach to travel time and crash risk, and the discount rate used to convert future costs and benefits into present equivalents. The effects of assuming growth in the value of travel time and price of fuel are also discussed. This is followed by tests relating to investment strategies, including the impact of applying some alternative Maintenance, Repair, and Rehabilitation (MR&R) strategies built into NBIAS, and the impact of alternative assumptions about future Operations/Intelligent Transportation System (ITS) deployment strategies in HERS. A subsequent section within this chapter explores information regarding the assumptions underlying the analyses developed using the Transit Economic Requirements Model (TERM).

Alternative Economic Analysis Assumptions

The U.S. Department of Transportation (DOT) periodically issues guidance on the valuation of travel time and the economic value of a statistical life, while the Office of Management and Budget (OMB) provides guidance to Federal agencies on the discount rate to be applied in benefit-cost analysis. Recognizing the uncertainty regarding these values, the guidance documents include both specific recommended values and ranges of values to be tested. The analyses presented in Chapter 7 and 8 of this report are based on the primary recommendations from the OMB and U.S. DOT guidance for these economic inputs, whereas the analyses presented in this chapter rely on recommended alternative values to be used for sensitivity testing.

The HERS analyses presented in Chapter 7 and 8 assume future changes in fuel prices consistent with forecasts from the U.S. Department of Energy's Annual Energy Outlook (AEO) publication. This publication presents a range of potential alternative forecasts. One such alternative assuming higher fuel prices is explored in this section.

Value of Travel Time

The value of travel time is a critical component of benefit-cost analysis of transportation investments. It is often the largest component of the benefits estimated. Time used for travel represents a cost to society and the economy because that time could be used for other more enjoyable or productive purposes. There is much debate on the appropriate value of travel time. Studies show that the value of time can vary by income, time of day and type of trip. The U.S. DOT's *Revised Departmental Guidance on the Value of Travel Time in Economic Analysis, 2011* recommends values of time to use for economic analysis developed from the findings of current research and the values used in other countries (see http://www.dot.gov/sites/dot.dev/files/docs/vot_guidance_092811c_0.pdf). The value of time is tied to specified percentages of the median annual household income for personal travel and the median gross wage for business travel, which vary

Why conduct a sensitivity analysis for the assumed value of travel time savings?

Sensitivity analysis is done to test the results of models using information that is uncertain, such as the value of travel time saved.

The U.S. DOT based its guidance for valuing travel time on a review of the research literature, which reflects estimates that vary widely even after attempts to standardize them. Particularly for personal travel (including commuting), the evidence is hard to synthesize. Internationally, common practice among transportation government agencies is to assume that the average value of personal travel time bears a fixed ratio to a measure of economy-wide average wages (or some similar measure).

For local personal travel, the value of travel time savings is estimated to be 50 percent of hourly median household income, derived by dividing the nationwide median annual household income by 2,080 hours to yield an hourly income. For business travel, the value of travel time savings is assumed to be equal to a nationwide median gross wage, defined as the sum of the median hourly wage and estimated hourly benefits.

The U.S. DOT recognizes the uncertainty in the recommended values and therefore recommends that alternative calculations be done using the range of high and low dollar values. For personal auto travel, the low value is 35 percent of the estimated hourly median household income and the high value is about 60 percent. For business travel, 80 percent of the median wage is used for the low dollar value and 120 percent is used for the high value.

depending on the mode of travel. Within the HERS and NBIAS models, the per-person-hour estimates of travel time savings based on this guidance are converted to average values of time per vehicle-hour for different types of vehicle classes, drawing upon estimates of average vehicle occupancy; time-related vehicle depreciation cost; and, for trucks, the inventory cost of freight in transit. For 2010, the average values per vehicle-hour ranged from $16.89 for small autos to $31.44 for five-axle combination trucks. (For the passenger vehicle classes, the averages are weighted means of a value for personal travel and a higher value for business travel.) The U.S. DOT guidance recommends sensitivity analyses using a lower and a higher value of travel time savings given the uncertainty of the values recommended; these alternative values are based on different valuations of travel time savings per person hour as a percentage of hourly earnings. *Exhibit 10-1* shows the results of applying these alternative travel time values to the average annual investment levels

Exhibit 10-1 Impact of Alternative Value of Time Assumptions on Highway Investment Scenario Average Annual Investment Levels

Alternative Assumptions About the Valuation of Travel Time Savings per Hour as a Percentage of Hourly Earnings, for Personal and Business Travel	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
	Billions of 2010 Dollars	Percent Change From Baseline	Billions of 2010 Dollars	Percent Change From Baseline
Baseline* (Personal–50%; Business–100%)	**$86.3**		**$145.9**	
HERS-Derived Component	$51.1		$86.9	
NBIAS-Derived Component	$12.2		$20.2	
Other (Non-modeled) Component	$23.0		$38.8	
Lower (Personal–35%; Business–80%)	**$89.2**	**3.3%**	**$134.9**	**-7.6%**
HERS-Derived Component	$53.2	4.0%	$78.9	-9.2%
NBIAS-Derived Component	$12.2	0.4%	$20.1	-0.5%
Other (Nonmodeled) Component	$23.7	3.3%	$35.9	-7.6%
Higher (Personal–60%; Business–120%)	**$84.9**	**-1.6%**	**$153.3**	**5.1%**
HERS-Derived Component	$50.1	-2.0%	$92.3	6.2%
NBIAS-Derived Component	$12.2	0.1%	$20.2	0.1%
Other (Nonmodeled) Component	$22.6	-1.6%	$40.8	5.1%

** The Baseline levels shown correspond to the systemwide scenarios presented in Chapter 8 that applied higher, HPMS-derived VMT growth forecasts. The investment levels shown are average annual values for the period from 2011 through 2030.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

associated with the **Maintain Conditions and Performance** scenario and the **Improve Conditions and Performance** scenario. Results are shown separately for the portions of these scenarios derived from HERS and NBIAS because their sensitivity to these inputs is very different. As discussed in Chapter 8, each scenario includes non-modeled investment components reflecting types of investments not modeled in HERS or NBIAS, which varies proportionally based on the model results.

Non-modeled Highway Investments

The HERS-derived component of each scenario represents spending on pavement rehabilitation and capacity expansion on Federal-aid highways. The NBIAS-derived component represents rehabilitation spending on all bridges, including those off the Federal-aid highways. The non-modeled component corresponds to system enhancement spending, plus pavement rehabilitation and capacity expansion on roads not classified as Federal-aid highways.

In the **Sustain 2010 Spending** scenario presented in Chapter 8, the values for these HERS and NBIAS components sum to $72.5 billion. In 2010, non-modeled spending accounted for 26.6 percent of total investment ($26.7 billion out of $100.2 billion) and is assumed to form the same share in all scenarios presented in Chapter 8.

Similarly for the sensitivity analysis for the **Maintain Condition and Performance** scenario and the **Improve Condition and Performance** scenario presented in this section, the non-modeled component is set at 26.6 percent of the total investment level. As the combined levels of the HERS-derived and NBIAS-derived scenario components rise or fall, the non-modeled component changes proportionally. Consequently, the percent change in the non-modeled component of each alternative scenario relative to the baseline always matches the percent change in the total investment level for that scenario.

Impact on Improve Conditions and Performance Scenario

As shown in *Exhibit 10-1*, applying a lower value of travel time reduces the average annual investment level for the **Improve Conditions and Performance** scenario from $145.9 billion to $134.9 billion (-7.6 percent). The HERS-derived component of the scenario declines by 9.0 percent from $86.9 billion to $78.9 billion, whereas the NBIAS-derived component declines by only 0.5 percent. Applying a higher value of time would increase the average annual investment level associated with this scenario by 5.5 percent in total, again with HERS investments being more sensitive, increasing by 6.2 percent.

The HERS investments are more sensitive to the value of travel time savings because the HERS model evaluates a mix of system rehabilitation and system expansion investments, and system expansion investments tend to be more sensitive to changes in travel time savings. NBIAS only considers system rehabilitation investments, which tend to have a much smaller impact on travel time, except to the extent that they address situations where weight restrictions had been imposed on a bridge requiring long detours for trucks.

As described in Chapter 8, the **Improve Conditions and Performance** scenario is defined to include all investments that would be cost-beneficial (i.e., with a benefit-cost ratio [BCR] greater than or equal to 1.00). The change in the value of travel time saved affects the benefits estimated. A reduction in the value of travel time saved is likely to reduce the magnitude of the benefits estimated from the time savings, thus reducing the BCR for individual projects under consideration. To the extent that the estimated BCR for some of these projects falls below 1.00, they would no longer qualify for inclusion under this scenario. Conversely, applying a higher value of time increases the estimated benefits and, hence, the BCR, causing more projects to appear to be cost-beneficial.

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Impact on Maintain Conditions and Performance Scenario

As described in Chapter 8, the **Maintain Conditions and Performance** scenario is intended to keep overall system conditions and performance in 2030 at roughly the same level as in 2010. The NBIAS-derived portion of this scenario is based on maintaining the average bridge sufficiency rating (see Chapter 7 for a discussion of this measure). The HERS-derived portion represents the average of two investment levels: (1) the amount of total HERS investment in system rehabilitation and system expansion that results in average pavement roughness (as measured by the International Roughness Index [IRI]) being maintained; and (2) an investment level which results in average delay per VMT being maintained. Generally, this approach results in one of these two indicators (IRI in the baseline analysis) improving a little over the 20-year period, while the other (delay in the baseline analysis) gets a little worse.

For the **Maintain Condition and Performance** scenario, applying a lower value of travel time savings increases the average annual investment level for HERS-derived component by 4.0 percent, from $51.1 billion to $53.2 billion. This change is primarily driven by changes in the mix of investments selected by HERS; reducing the value of time makes capacity projects less attractive, so that HERS will direct a greater share of investment towards pavement rehabilitation. This has the effect of reducing the level of total HERS investment required to maintain average pavement roughness, while increasing the level of total HERS investment required to maintain average delay. In this case, these changes were not proportional, causing the average of these two HERS investment levels to rise. The opposite is true applying a higher value of travel time savings, which brings the investment level associated with maintaining average pavement roughness closer to the investment level associated with maintaining average delay, and reduces their average by 2.0 percent relative to the baseline.

The NBIAS-derived component of the **Maintain Condition and Performance** scenario rounds to $12.2 billion regardless of which set of travel time assumptions is applied. The overall investment level associated with this scenario would increase by 3.3 percent, from $86.3 billion to $89.2 billion, assuming a lower value of time, and decline by 1.6 percent to $84.9 billion assuming a higher value of time.

Growth in the Value of Time

Benefit cost analysis is generally done in constant base year dollars, assuming no change in the value of the parameters used in the analysis. The implicit assumption of this approach is that all values will experience the same rate of growth in the future, therefore not changing the relative values. U.S. DOT guidance recommended value for travel time savings is based on the median national gross hourly wage for business travel and the median hourly household income for personal travel. The guidance also recognizes the need to increase the value of travel time savings in line with the growth in income adjusted for inflation. It assumes income elasticity equal to one for scaling the value of travel time savings, based on time series estimates of income elasticity. The recommendation is that the value of travel time savings increases annually by 1.6 percent based on Congressional Budget Office assumption of future annual growth in real median household income.

This poses a few challenges on how to appropriately include the increase in the real value of time. The value of time will affect both the demand for travel and the value of the benefits estimated. Since the real value of time increases due to an increase in income, this would increase the demand for travel given income elasticity of demand for travel, possibly in addition to the other changes. However, as HERS is currently configured, the base year value of time is factored into the implicit baseline price that the model assumes is consistent with the HPMS-derived VMT growth forecast. If the value of time is increased over time, the HERS model will interpret the resulting increase in travel time costs relative to the base year the same way it would if this increase in costs were related to increased congestion. Consequently, the travel demand elasticity feature in HERS will cause some of the HPMS-derived future VMT growth to be suppressed.

Q&A

What are some examples of the types of behavior that the travel demand elasticity features in HERS represent?

If highway congestion worsens in an area, this increases travel time costs on the road network. In response, some highway users might shift their trips to mass transit or perhaps forgo some personal trips that they might ordinarily make. For example, they might be more likely to combine multiple errands into a single trip because the time spent in traffic discourages them from making a trip unless it is absolutely necessary. Increases in fuel prices also increase the cost of driving and would have a similar impact.

In the longer term, people might make additional adjustments to their lifestyles in response to changes in user costs that would impact their travel demand. For example, if travel time in an area is reduced substantially for an extended period of time, some people may make different choices about where to purchase a home. If congestion is reduced, purchasing a home far out in the suburbs might become more attractive because commuters would be able to travel farther in a shorter period of time.

Exhibit 10-2 illustrates the effect of including an increase in the real value of time in HERS as it is currently configured. Under the **Improve Conditions and Performance** scenario, the growth in the value of time increases the HERS-modeled component of the average annual investment level from $86.9 billion to $87.7 billion, a 0.9 percent change. Projected 2030 Federal-aid highway VMT would be 3.544 trillion under this alternative, rather than the 3.629 trillion predicted for 2030 in the baseline analysis. The reduction in travel demand reduces the net time savings and pavement improvements resulting from the investments, while the value of time estimate increases. The two countervailing impacts have a very small effect on the estimated benefits, and hence the resulting investment needs.

Exhibit 10-2 **Impact of Alternative Assumptions About Growth in the Real Value of Time on Highway Investment Scenario Average Annual Investment Levels**

Alternative Assumptions About Growth in Value of Time in Response to Projected Increases in Real Median Household Income	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
	Billions of 2010 Dollars	Percent Change From Baseline	Billions of 2010 Dollars	Percent Change From Baseline
Baseline* (No change)	**$86.3**		**$145.9**	
HERS-Derived Component	$51.1		$86.9	
Alternative (1.6 % increase per year)	**$77.8**	**-9.8%**	**$147.0**	**0.8%**
HERS-Derived Component	$44.9	-12.2%	$87.7	0.9%

** The Baseline levels shown correspond to the systemwide scenarios presented in Chapter 8 that applied higher, HPMS-derived VMT growth forecasts. The investment levels shown are average annual values for the period from 2011 through 2030.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

For the **Maintain Conditions and Performance** scenario, the average annual investment level associated with the HERS-derived component would fall from $51.1 billion to $44.9 billion under this alternative, a 12.2 percent decline. The investment associated both with maintaining average pavement roughness and average delay per VMT would be lower under this alternative—projected 2030 Federal-aid highway VMT would be 3.489 trillion, down from 3.584 trillion in the baseline analysis. The increased value of time tends to increase the BCR associated with some projects, which has an impact on the prioritized ranking of potential projects, but this effect is swamped by the HERS perception that any increase in travel time costs equates to a higher implicit price and, consequently, less travel.

The initial plans for this report had been to factor in an increasing value of time into the baseline analysis, as directed by U.S. DOT guidance. However, as a result of HERS testing similar to that presented above, this increased value was not included in the analysis for this report, and instead to work on alternative approaches that would better capture the impacts of higher incomes without unintentionally suppressing travel growth. The NBIAS model does not currently have the capability to process changes to the value of time during its analysis period.

Value of a Statistical Life

One of the most challenging issues in benefit-cost analysis is how to best determine the monetary cost to place on injuries of various severities. Few people would consider any amount of money to be adequate compensation for a person being seriously injured, much less killed. On the other hand, people can attach a value to changes in their risk of suffering an injury, and indeed such valuations are implicit in their everyday choices. For example, a traveler may face a choice between two travel options that are equivalent except that one carries a lower risk of fatal injury but costs more. If the additional cost is $1, then a traveler who selects the safer option is manifestly willing to pay at least $1 for the added safety—what economists call "revealed preference." Moreover, if the difference in risk is, say, one in a million, then a million travelers who select the safer option are collectively willing to pay at least $1 million for a risk reduction that statistically can be expected to save one of their lives. In this sense, the "value of a statistical life" among this population is at least $1 million.

Based on the results of various studies of individual choices involving money versus safety trade-offs, some government agencies estimate an average value of a statistical life (VSL) for use in their regulatory and investment analyses. The U.S. DOT issued guidance in 2008 (Revised Departmental Guidance: Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses) recommending a value of $5.8 million per statistical life, to be updated annually by the changes in prices and income. The 2010 inflated VSL is $6.2 million. (Subsequent to the analysis undertaken for this report, guidance issued by the DOT in 2013 increased the VSL to $9.1 million for analyses with a base year of 2012 [Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses, http://www.dot.gov/office-policy/transportation-policy/guidance-treatment-economic-value-statistical-life].) For nonfatal injuries, the DOT retained from its 1993 guidance the practice of setting values per statistical injury as percentages of the value of a statistical life; these vary according to the level of severity, from 0.2 percent for a "minor" injury to 76.3 percent for a "critical" injury. (The injury levels are from the Maximum Abbreviated Injury Scale.) In view of the uncertainty surrounding the average value of a statistical life, the Department also required that regulatory and investments analyses include sensitivity tests using alternative values; alternative values of $3.4 million as the lower bound and $9.0 million as the upper bound are presented.

Impact of Alternatives on HERS Results

The HERS model contains for each highway functional class equations to predict crash rates per VMT and parameters to determine the number of fatalities and nonfatal injuries per crash. The model assigns to crashes involving fatalities and other injuries an average cost consistent with the guidance in the U.S. DOT memorandum. *Exhibit 10-3* demonstrates that the results from the HERS simulations are nevertheless relatively insensitive to the use of alternative values of a statistical life. This is consistent with the observations from Chapter 7 that crash costs: (1) form a small share of highway user cost (13.6 percent in 2010); and (2) are much less sensitive than travel time and vehicle operating costs to changes in the level of total investment within the scope of HERS, which excludes targeted safety-oriented investments due to data limitations. Replacing the baseline value of a statistical life with a figure of $9.0 million slightly raises the BCR for potential improvements and increases the estimate of the amount of potentially cost-beneficial investment (the HERS component of the **Improve Conditions and Performance** scenario) by 0.9 percent, from $86.9 billion to $87.7 billion. Conversely, assuming a value of statistical life of $3.4 million would reduce the average annual investment level associated with the HERS-derived component of the scenario by 0.7 percent.

For the **Maintain Conditions and Performance** scenario, increasing (to $9.0 million) or lowering (to $3.4 million) the average value of a statistical life would change the average annual investment level by negative 0.8 percent or positive 0.5 percent respectively.

Exhibit 10-3 **Impact of Alternative Value of Life Assumptions on Highway Investment Scenario Average Annual Investment Levels**

Alternative Value of a Statistical Life Assumption, in 2010 Dollars	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
	Billions of 2010 Dollars	Percent Change From Baseline	Billions of 2010 Dollars	Percent Change From Baseline
Baseline* ($6.2 Million)	**$86.3**		**$145.9**	
HERS-Derived Component	$51.1		$86.9	
NBIAS-Derived Component	$12.2		$20.2	
Other (Non-modeled) Component	$23.0		$38.8	
Lower ($3.4 Million)	**$84.5**	**-2.1%**	**$142.4**	**-2.4%**
HERS-Derived Component	$50.7	-0.8%	$86.3	-0.7%
NBIAS-Derived Component	$11.3	-7.6%	$18.2	-9.8%
Other (Non-modeled) Component	$22.5	-2.1%	$37.9	-2.4%
Higher ($9.0 Million)	**$87.7**	**1.7%**	**$148.9**	**2.0%**
HERS-Derived Component	$51.4	0.5%	$87.7	0.9%
NBIAS-Derived Component	$13.0	6.5%	$21.5	6.7%
Other (Non-modeled) Component	$23.4	1.7%	$39.6	2.0%

** The Baseline levels shown correspond to the systemwide scenarios presented in Chapter 8 that applied higher, HPMS-derived VMT growth forecasts. The investment levels shown are average annual values for the period from 2011 through 2030.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

Impact of Alternatives on NBIAS Results

Exhibit 10-3 also shows that increasing the assumed value of a statistical life to $9.0 million raises the NBIAS estimate of the average annual investment in bridges that would be needed over the following 20 years to fund all cost-beneficial projects by 2030 (the NBIAS component of the **Improve Conditions and Performance** scenario) by 6.7 percent, from $20.2 billion to $21.5 billion. Assuming a higher value of life increases the benefits associated with projects that reduce crash rates, causing additional projects to have a BCR above 1.0. Conversely, reducing the statistical value of life to $3.4 million reduces the NBIAS-derived component of the **Improve Conditions and Performance** scenario by 9.8 percent, indicating that there are a number of projects with BCRs not far above 1.0 in the baseline analysis that derived benefits from reducing crash rates.

At any given level of investment, increasing the value of statistical life shifts investment toward producing significant safety benefits to bridge users (by reducing crash rates) and away from projects that may be more focused on addressing issues with the physical conditions of bridges. Consequently, the overall level of NBIAS investment associated with maintaining the average bridge sufficiency rating is 6.5 percent higher ($13.0 billion versus $12.2 billion per year) assuming a $9.0 million value of a statistical life than in the baseline analysis. Assuming a $3.4 million value of a statistical life reduces the average annual NBIAS-derived component of the **Maintain Conditions and Performance** scenario by 7.6 percent, because a greater share of this spending is directed towards projects that would more directly impact the sufficiency rating.

Discount Rate

Benefit-cost analyses use a discount rate that scales down benefits and costs arising in the future relative to those arising in the base year. To this point, the real discount rate has been 7 percent in this report's applications of HERS, NBIAS, and TERM; this means that deferring a benefit or cost for a year reduces its real value by approximately 6.5 percent (1/1.07). This choice of real discount rate conforms to the "default position" in the 1992 OMB guidance on discount rates, in Circular A-94, for benefit-cost analyses of public investment and regulatory programs. Subsequently, in 2003, OMB's Circular A-4 recommended that

Could the discount rate be higher than 7 percent?

Q&A

The 2003 OMB guidance calls for the use of a discount rate higher than 7 percent as a further sensitivity test in some instances. In the context of public investment, this recommendation applies when there is a fair likelihood that: (1) much of the investment's opportunity cost will take the form of crowding out private investment, and (2) the displaced investment would have generated an average real rate of return exceeding 7 percent annually. Although the first of these conditions could be valid for some public investments in highways and transit systems, the expectation that displaced private investments will average rates of return above 7 percent annually could be difficult to justify. In 2003, the OMB referred to its own recent estimate that the average real rate of return on private investment remained near the 7 percent that the OMB had estimated in 1992. Although the OMB also noted that the average real rate of return on corporate capital in the United States was approximately 10 percent in the 1990s, it is by no means clear whether the current economic outlook could justify the expectation of a rate of return averaging above 7 percent during this report's analysis period.

regulatory analyses use both 3 percent and 7 percent as alternative discount rates (http://www.whitehouse.gov/sites/default/files/omb/assets/omb/circulars/a004/a-4.pdf). The justifications for these recommendations apply equally to benefit-cost analyses of public investments, so the sensitivity tests in this section include the use of the 3-percent discount rate as an alternative to the 7-percent rate used in the baseline simulations.

Alternative Discount Rates—HERS

When the goal is to select all cost-beneficial improvements, as is the case for the **Improve Conditions and Performance** scenario, changing the discount rate from 7 percent to 3 percent increases the amount of investment in HERS programs by 21.6 percent, with the annual average amount increasing from $86.9 billion to $105.7 billion over the period from 2011 to 2030 *Exhibit 10-4*). This increase in investment dollars results in more favorable projections for highway conditions and performance in 2030. The lowering of the discount rate improves the projection for average pavement roughness by 5.8 percentage points (from a 26.4 percent reduction to a 32.2 percent reduction) and average delay by 3.7 percentage points (from an 8.0 percent reduction to an 11.7 percent reduction).

In addition to increasing the amount of investment that can be economically justified, the reduction in assumed discount rate shifts the HERS allocation of any given investment, in particular toward improvements that produce relatively long streams of future benefits. This shift in investment patterns would result in a small (2.7 percent) increase in the HERS-derived component of the **Maintain Conditions and Performance** scenario.

Exhibit 10-4 Impact of Alternative Discount Rate Assumption on Highway Investment Scenario Average Annual Investment Levels

Alternative Assumptions About Discount Rate	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
	Billions of 2010 Dollars	Percent Change From Baseline	Billions of 2010 Dollars	Percent Change From Baseline
Baseline* (7% discount rate)	**$86.3**		**$145.9**	
HERS-Derived Component	$51.1		$86.9	
NBIAS-Derived Component	$12.2		$20.2	
Other (Non-modeled) Component	$23.0		$38.8	
Alternative (3% discount rate)	**$88.1**	**2.1%**	**$177.3**	**21.5%**
HERS-Derived Component	$52.5	2.7%	$105.7	21.6%
NBIAS-Derived Component	$12.2	-0.3%	$24.4	20.7%
Other (Non-modeled) Component	$23.5	2.1%	$47.2	21.5%

** The Baseline levels shown correspond to the systemwide scenarios presented in Chapter 8 that applied higher, HPMS-derived VMT growth forecasts. The investment levels shown are average annual values for the period from 2011 through 2030.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

Alternative Discount Rates—NBIAS

Since many of the bridge improvements evaluated in NBIAS are relatively long-lived, the choice of discount rate can significantly affect the model's estimate of investments necessary to maintain or improve the condition and performance of the system. Reducing the discount rate increases the number of potential investments that pass the benefit cost test. *Exhibit 10-4* shows that reducing the real discount rate in NBIAS from the baseline 7 percent to 3 percent would increase the NBIAS-derived component of the **Improve Conditions and Performance** scenario by 20.7 percent, from $20.2 billion to $24.4 billion, annually.

For the maintain scenario, the BCR is not the limiting factor or the goal. Many projects that pass the benefit test will not be included under the maintain scenario, so increasing the number of eligible projects does not significantly affect the needs estimated. The change in discount rate would change the composition of investments implemented in NBIAS, which would result in a 0.3 percent reduction in the NBIAS-derived component for the **Maintain Conditions and Performance** scenario.

Alternative Future Fuel Price Assumptions

In this edition of the C&P report, the price of oil used in the baseline analyses presented in Chapters 7 and 8 is the AEO reference forecast. This is a change from the 2010 C&P report where price of oil was held constant at the base year level. From 2008 to 2010 the price of fuel (both gasoline and diesel) declined by 38.5 percent. AEO projects oil prices to increase above the rate of inflation and anticipates that, after recovering in 2011, fuel prices will ease up for a few years and then start to increase above the rate of inflation, resulting in an increase of 28.2 percent over the first 5 years of the C&P analysis period, and a 45.0 percent increase over the 20-year period.

The sensitivity analysis presented in *Exhibit 10-5* compares the changes in investment needs using AEO's projections assuming a more aggressive rate of growth in prices. Under this projection, the oil prices continue to increase, resulting in 93.1 percent growth in the first 5 years, with a total increase of 162.6 percent over the 20-year period. *Exhibit 10-5* shows the results of using a more aggressive rate of growth in oil prices. For the **Improve Conditions and Performance** scenario, the average annual investment level would decline by 14.7 percent, driven by a decline in the HERS-modeled component of 18.1 percent. For the **Maintain Conditions and Performance** scenario, the average annual investment level would decline from $86.3 billion to $72.8 billion, a reduction of 15.7 percent, driven by a decline in the HERS-modeled component of 19.4 percent. Under both scenarios, the reduction in investments results primarily from reduced spending on system expansion. This sensitivity test was not applied to NBIAS, as it does not include fuel prices as a separate discrete model input.

Exhibit 10-5 Impact of Alternative Future Fuel Price Assumption on Highway Investment Scenario Average Annual Investment Levels

Alternative Assumptions About Future Fuel Prices	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
	Billions of 2010 Dollars	Percent Change From Baseline	Billions of 2010 Dollars	Percent Change From Baseline
Baseline* (AEO Reference Case)	**$86.3**		**$145.9**	
HERS-Derived Component	$51.1		$86.9	
Alternative (AEO High Oil Price Case)	**$72.8**	**-15.7%**	**$124.5**	**-14.7%**
HERS-Derived Component	$41.2	-19.4%	$71.2	-18.1%

** The Baseline levels shown correspond to the systemwide scenarios presented in Chapter 8 that applied higher, HPMS-derived VMT growth forecasts. The investment levels shown are average annual values for the period from 2011 through 2030.*

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

Assuming a higher rate of growth in oil prices increases the user costs by increasing the cost of driving. As discussed in Chapter 7, an increase in user costs lead to reduced miles of travel. Under the **Maintain Conditions and Performance** scenario, projected 2030 VMT on Federal-aid highways would be 8.1 percent lower (3.293 trillion vs. 3.584 trillion) relative to the baseline assumption. Under the **Improve Conditions and Performance** scenario, VMT would be 8.2 percent lower assuming higher fuel prices than in the baseline.

Alternative Strategies

In addition to analyses based on alternative technical assumptions, the HERS and NBIAS models are capable of analyzing selected policy alternatives as well. Two such alternatives pertain to strategies for bridge MR&R (modeled in NBIAS), and accelerating the future rate of deployment of Operations/ITS strategies.

Alternative Bridge Maintenance, Repair, and Rehabilitation Strategies

As discussed in Appendix B, the NBIAS model has been adapted to consider four alternative strategies for the MR&R actions simulated in NBIAS. The State of Good Repair MR&R strategy is the most aggressive, and seeks to bring all bridges to a relatively high condition level that can be sustained via ongoing investment, and involves heavy frontloading of MR&R spending. The Sustain Steady State MR&R strategy is somewhat less aggressive, and is aimed toward identifying and implementing a pattern of MR&R improvements that would reach and achieve an improved steady state in terms of overall bridge system conditions without frontloading MR&R investment. The Maximize Average Returns strategy is even less aggressive, seeking to maximize the degree of bridge system performance improved per dollar of MR&R expenditure. The least aggressive alternative is the Minimize MR&R Costs strategy, which seeks to minimize MR&R costs only, without regard to the implications for other types of NBIAS-modeled spending. The baseline analyses presented in Chapters 7 and 8 applied the Sustain Steady State MR&R strategy; previous C&P reports relied on the Minimize MR&R Costs strategy.

As discussed in Chapter 7, the NBIAS model considers bridge deficiencies at the level of individual bridge elements based on engineering criteria and computes an initial value for the cost of a set of corrective actions that would address all such deficiencies. The economic bridge investment backlog represents the combined cost of these corrective actions in those cases where NBIAS estimates that it would be cost-beneficial to implement them. Assuming the Sustain Steady State MR&R strategy, the economic backlog for year 2010, as reported in Chapter 7, was estimated to be $106.4 billion. *Exhibit 10-6* shows that, if less-aggressive MR&R strategies are assumed, the size of the initial backlog would be smaller. Reducing the set of MR&R actions considered results in an estimated 2010 backlog of $93.4 billion assuming the Minimize MR&R Costs strategy and $100.8 assuming the Maximize Average Return strategy. Assuming the more aggressive State of Good Repair MR&R strategy would increase the 2010 backlog computed by NBIAS to $114.3 billion.

Although the Minimize MR&R Costs strategy has the lowest initial backlog from among the four alternatives, the average annual investment level associated with implementing all cost-beneficial NBIAS modeled investment within the **Improve Conditions and Performance** scenario is $31.6 billion, 56.3 percent higher than the $20.2 billion level estimated in the baseline. Even this level of investment is insufficient to maintain the average sufficiency rating at its 2010 level of 81.7 on a scale of zero to 100; the projected average sufficiency rating for 2030 would be only 75.4. Thus, it is not possible to achieve the objective of the **Maintain Conditions and Performance** scenario assuming a Minimize MR&R Cost strategy. The implications of these findings are that skimping on MR&R spending in the short term may make it necessary to conduct major bridge rehabilitation actions or bridge replacements sooner than would have been the case had MR&R spending been more robust.

Exhibit 10-6 shows similar results when the Maximize Average Returns MR&R strategy is applied. The criteria for the **Maintain Conditions and Performance** scenario cannot be met. Applying this strategy results in an average annual investment level of $31.7 billion for the NBIAS-derived component of the **Improve Conditions and Performance** scenario.

Exhibit 10-6 Impact of Alternative Bridge Maintenance, Repair, and Rehabilitation Strategies on the Economic Bridge Investment Backlog and Future Capital Investment Scenarios

Alternative Maintenance, Repair, and Rehabilitation (MR&R) Strategies	2010 Economic Bridge Investment Backlog[1]	Average Annual Highway Capital Investment, 2011 Through 2030 (Billions of 2010 Dollars)			
		Maintain Conditions and Performance Scenario[2]		Improve Conditions and Performance Scenario	
		NBIAS-Modeled	Total	NBIAS-Modeled	Total
Sustain Steady State (2013 C&P Baseline)	**$106.4**	**$12.2**	**$86.3**	**$20.2**	**$145.9**
Minimize MR&R Costs (2010 C&P Baseline)	$93.4	N/A	N/A	$31.6	$161.4
Maximize Average Returns	$100.8	N/A	N/A	$31.7	$161.6
State of Good Repair	$114.3	$10.0	$83.3	$20.8	$146.8

[1] *When future MR&R strategies are assumed to be less aggressive, the MR&R-related component of the initial backlog is reduced.*

[2] *N/A indicates that the maximum amount of cost-beneficial investment identified by NBIAS under the **Improve Conditions and Performance** scenario was insufficient to maintain the average sufficiency rating at its base-year level of 81.7; thus, the criteria for the **Maintain Conditions and Performance** scenario cannot be met.*

Source: National Bridge Investment Analysis System.

Applying the State of Good Repair MR&R strategy reduces the cost of maintaining the average sufficiency rating relative to the baseline, resulting in an average annual investment level of $10.0 billion over 20 years for the NBIAS component of the **Maintain Conditions and Performance** scenario. Use of this MR&R strategy would result in a small increase in the annual NBIAS component of the **Improve Conditions and Performance** scenario relative to the baseline ($20.8 billion versus $20.2 billion), but would result in a higher average sufficiency rating in 2030 relative to the baseline (86.0 versus 84.6).

Accelerating Operations/ITS Deployments

As described in Chapter 7, the HERS model considers the impacts on highway conditions and performance of various types of ITS and other operational enhancements to highways. Appendix A describes the types of strategies considered (including arterial management, freeway management, incident management, and traveler information systems) and three scenarios for future deployment. Although HERS incorporates assumptions about future deployment, it does not subject operational enhancements to benefit-cost analysis or to other economic evaluation; hence, the preceding chapters in this report referred to spending on these and other system enhancements as non-modeled. The only spending that HERS models in this sense is on highway pavement rehabilitation and capacity expansion, although spending on operational enhancements is represented.

Impact on Maintain Conditions and Performance Scenario

In the **Maintain Conditions and Performance** scenario, annual spending on HERS-modeled improvements averaged $51.1 billion under the baseline assumptions about future deployment of operational improvements. If HERS-modeled spending were held at that level while future deployment of operational improvements were assumed to be more aggressive, overall conditions and performance in 2030 relative to 2010 would be improved rather than maintained. To attain the scenario goal**,** HERS-modeled spending must therefore be lower when the alternative deployment assumptions replace the baseline.
For the "aggressive" deployment alternative, *Exhibit 10-7* shows the HERS-modeled capital spending to average $49.7 billion per year and spending on operational enhancements (including capital, operations

and maintenance costs) to be $4.6 billion per year more than in the baseline. The sum of these figures, $54.3 billion, indicates a $3.2 billion increase in total spending relative to the baseline value of $51.1 billion to achieve the objectives of the **Maintain Conditions and Performance** scenario. For the "full immediate deployment alternative," total spending is $55.1 billion, or $4.0 billion higher than the baseline value.

Exhibit 10-7 Impact of Alternative Operations Strategies Deployment Rate Assumptions on Selected Performance Indicators and Highway Investment Scenarios

Operations/ITS Deployments Assumption[1]	Average Annual Highway Investment, 2011 Through 2030 (Billions of 2010 Dollars)				Percent Change, 2030 Compared With 2010	
	HERS-Derived Component					
	HERS Modeled Spending	Additional Deployment Spending[2]	Total HERS	Total	Average Pavement Roughness (IRI)	Average Delay per VMT
Maintain Conditions and Performance Scenario						
Baseline[3] (continue existing trends)	**$51.1**	**N/A**	**$51.1**	**$86.3**	**-7.6%**	**4.3%**
Aggressive deployments alternative	$49.7	$4.6	$54.3	$90.6	-6.6%	3.3%
Full immediate deployments alternative	$45.0	$10.1	$55.1	$91.7	-1.9%	3.5%
Improve Conditions and Performance Scenario						
Baseline[3] (continue existing trends)	**$86.9**	**N/A**	**$86.9**	**$145.9**	**-26.7%**	**-8.0%**
Aggressive deployments alternative	$86.4	$4.6	$91.0	$151.5	-26.7%	-9.3%
Full immediate deployments alternative	$86.4	$10.1	$96.5	$159.0	-27.0%	-11.0%
Average Annual Spending $145.9 Billion						
Baseline[3] (continue existing trends)	**$86.9**	**N/A**	**$86.9**	**$145.9**	**-26.7%**	**-8.0%**
Aggressive deployments alternative	$82.3	$4.6	$86.9	$145.9	-25.3%	-8.1%
Full immediate deployments alternative	$76.8	$10.1	$86.9	$145.9	-22.8%	-8.7%

[1] The analyses presented in this table assume one of the following: (1) existing trends in ITS deployments will continue for 20 years; (2) an aggressive pattern of deployment will occur over the next 20 years; or (3) all of the aggressive deployments will occur immediately, rather than being spread out over 20 years. The costs associated with the more aggressive deployments were deducted from the budget available in HERS for pavement and widening investments.

[2] Amounts reflect additional capital and operation and maintenance costs associated with the alternative Operations/ITS deployment strategies relative to the Baseline.

[3] The Baseline levels shown correspond to the systemwide scenarios presented in Chapter 8 that applied higher, HPMS-derived VMT growth forecasts.

Source: Highway Economic Requirements System.

By design, under any of the deployment assumptions, the **Maintain Conditions and Performance** scenario shows no unambiguous change in overall conditions and performance relative to the baseline. An improvement in one of the scenario's measures of conditions and performance must be accompanied by deterioration in the other measure. Under each deployment assumption, the measure which shows improvement happens to be average pavement roughness; at the same time, average delay per VMT worsens. Assuming aggressive rather than baseline deployment makes the projected change less favorable for average pavement roughness (-6.6 percent versus -7.6 percent) but more favorable for average delay (3.3 percent versus 4.3 percent). The projections for average delay are more favorable because the types of operational improvements represented are assumed to have direct impacts only on travel time and accident rates; direct impacts on pavement conditions are assumed to be negligible.

These findings suggest that at the particular investment level reflected in the Maintain Conditions and Performance scenario (which is 13.9 percent below the actual level of spending by all levels of government in 2010), diverting resources from pavement and capacity improvements towards more aggressive deployment of operational improvements would not produce better conditions and performance outcomes. It should be noted however, that some of the operational improvements being considered, such as incident management systems, have benefits in crash reductions that would not be reflected in the IRI and delay measures used as targets in the **Maintain Conditions and Performance** scenario**.**

Impact on Improve Conditions and Performance Scenario

In the **Improve Conditions and Performance** scenario**,** more aggressive deployment of operational enhancements marginally reduces the amount of highway rehabilitation and capacity investment that HERS finds to be cost-beneficial. HERS-modeled rehabilitation and capacity investment decreases from $86.9 billion per year assuming baseline deployment to $86.4 billion per year assuming either of the more aggressive deployment alternatives. Total spending represented in HERS increases, however, because of the extra spending on the operations deployments, from $86.9 billion per year in the baseline to $96.5 billion per year assuming full immediate deployments. After adding an allowance for capital spending on non-modeled improvements, *Exhibit 10-7* indicates the corresponding variation in total spending to be between $145.9 billion per year in the baseline and $159.0 billion per year assuming full immediate deployments.

Because of the increased spending on operational enhancements, projections for average delay are more favorable when deployment is more aggressive than when the baseline is assumed. Although the types of operational enhancements considered in these cases are assumed to have no direct impacts on pavement quality, the projections for average pavement roughness are also slightly better than in the baseline. One reason for this is that spending on pavement rehabilitation is slightly higher under more aggressive deployment even though total HERS-modeled spending is lower. Pavement rehabilitation receives $44.3 billion out of the total $86.4 billion in HERS-modeled spending under the full immediate deployment alternative, versus $43.9 billion out $86.9 billion in the baseline.

Although these findings suggest that adopting more aggressive Operations/ITS deployment strategies would be advantageous if overall highway spending levels were significantly increased, the different levels of investment associated with each of these alternatives under the **Improve Conditions and Performance** scenario make direct tradeoffs more difficult to assess. To address this issue, the bottom three rows in *Exhibit 10-7* present alternative allocations of fixed total spending between the HERS-modeled types of improvements and operational enhancements given a single fixed level of HERS investment, based on the $86.9 billion HERS-derived component of the **Improve Conditions and Performance** scenario. The additional spending on operational improvements in the more aggressive deployment alternatives is assumed to come out of this total, reducing dollar-for-dollar the HERS-modeled component of spending. The balance of this spending offset between pavement rehabilitation and highway capacity expansion is determined by the model's cost-benefit optimization.

Exhibit 10-7 indicates that such reallocation of spending would produce worse outcomes in 2030 for pavement roughness, but better outcomes for travel delay. For pavement roughness, this reflects reduced spending on pavement rehabilitation together with operational enhancements being assumed to have no direct effect. For average delay, the reduction from the additional spending on operational enhancements outweighs the effect of the offset to spending on highway capacity. With the full immediate deployment assumed, pavements are projected to become 22.8 percent smoother between 2010 and 2030, compared with 26.7 percent smoother with baseline deployment assumed. For average delay per VMT, the corresponding projections are for reductions of 8.7 percent versus 8.0 percent.

Transit Sensitivity Analysis

This section examines the sensitivity of the Transit Economic Requirements Model's (TERM's) transit investment needs estimates to variations in the values of these key inputs:

- Asset Replacement Timing (Condition Threshold)
- Capital Costs
- Value of Time
- Discount Rate.

Specifically, these alternative projections assess how the estimates of baseline investment needs for the **State of Good Repair (SGR) Benchmark** and the **Low Growth** and **High Growth Scenarios** discussed in Chapter 8 vary in response to changes in the assumed values of these input variables. Note here that, by definition, funding under the **Sustain 2010 Spending Scenario** is invariant to changes in any input variable and, for this reason, that scenario is not considered in this sensitivity analysis.

Changes in Asset Replacement Timing (Condition Threshold)

Each of the four investment scenarios examined in Chapter 8 assume that assets are replaced at condition rating 2.50 as determined by TERM's asset condition decay curves (in this context, 2.50 is referred to as the "replacement condition threshold"). Recall here that TERM's condition rating scale runs from 5.0 for assets in "excellent" condition through 1.0 for assets in "poor" condition. In practice, this assumption implies replacement of assets within a short-term period (e.g., roughly 1 to 5 years depending on asset type) *after* they have attained their expected useful life. Replacement at condition 2.50 can therefore be thought of as providing a replacement schedule that is both realistic (in practice, few assets are replaced exactly at their expected useful life value due to a range of factors including the time to plan, fund, and procure an asset replacement) and potentially conservative (i.e., the needs estimates would be higher if all assets were assumed to be replaced at precisely the end of their expected useful life).

Based on this background, *Exhibit 10-8* shows the impact of varying the replacement condition threshold by increments of 0.25 on TERM's projected asset *preservation* needs for the **SGR Benchmark** and the **Low**

Exhibit 10-8 Impact of Alternative Replacement Condition Thresholds on Transit Preservation Investment Needs by Scenario (Excludes Expansion Impacts)

	SGR Benchmark		Low Growth Scenario		High Growth Scenario	
Replacement Condition Thresholds	Billions of 2010 Dollars	Percent Change From Baseline	Billions of 2010 Dollars	Percent Change From Baseline	Billions of 2010 Dollars	Percent Change From Baseline
Very late asset replacement (2.00)	$15.57	-15.7%	$14.68	-13.7%	$14.77	-13.7%
Replace assets later (2.25)	$17.33	-6.1%	$16.00	-5.9%	$16.13	-5.8%
Baseline (2.50)	$18.46		$17.01		$17.12	
Replace assets earlier (2.75)	$22.07	19.6%	$20.16	18.5%	$20.41	19.2%
Very early asset replacement (3.00)	$26.03	41.0%	$23.28	36.9%	$23.49	37.2%

Source: Transit Economic Requirements Model.

Growth and **High Growth Scenarios**. It should be noted that selection of a higher replacement condition threshold results in assets being replaced at a higher condition (i.e., at an earlier age), which in turn reduces the length of each asset's service life, thus increasing the number of replacements over any given period of analysis and driving up scenario costs. Reducing the replacement condition threshold will, of course, have the opposite effect. As shown in *Exhibit 10-8*, each of these three scenarios shows significant changes to total estimated preservation needs from quarter point changes in the replacement condition threshold. Relatively small changes in the replacement condition threshold frequently translate into significant changes in the expected useful life of some asset types; hence, small changes can also drive significant changes in replacement timing and replacement costs.

Changes in Capital Costs

The asset costs used in TERM are based on actual prices paid by agencies for capital purchases as reported to Federal Transit Administration (FTA) in the Transit Electronic Award Management (TEAM) System and in special surveys. Asset prices in the current version of TERM have been converted from the dollar year replacement costs in which assets were reported to FTA by local agencies (which vary by agency and asset) to 2010 dollars using RSMeans© construction cost index. Given the uncertain nature of capital costs, a sensitivity analysis has been performed to examine the effect that higher capital costs would have on the dollar value of TERM's baseline projected transit investment.

As shown in *Exhibit 10-9,* TERM projects that a 25 percent increase in capital costs (i.e., beyond the 2010 level used for this report) would be fully reflected in the **SGR Benchmark,** but only partially realized under either the **Low Growth** or **High Growth Scenarios**. This difference in sensitivity results is driven by the fact that investments are not subject to TERM's benefit-cost ratio in computing the **SGR Benchmark** (i.e., there are no consequences to increasing costs), whereas the two cost-constrained scenarios do employ this test. Hence, for the **Low Growth** or **High Growth Scenarios**, any increase in capital costs (without a similar increase in the value of transit benefits) results in lower benefit-cost ratios and the failure of some investments to pass this test. Therefore, for these latter two scenarios, a 25 percent increase in capital costs would yield a range of roughly 19 to 20 percent increase in needs that pass TERM's benefit-cost test.

Exhibit 10-9 Impact of an Increase in Capital Costs on Transit Investment Estimates by Scenario

	SGR Benchmark		Low Growth Scenario		High Growth Scenario	
Capital Cost Increases	Billions of 2010 Dollars	Percent Change From Baseline	Billions of 2010 Dollars	Percent Change From Baseline	Billions of 2010 Dollars	Percent Change From Baseline
Baseline (no change)	$18.46		$21.96		$24.54	
Increase Costs 25%	$23.08	25.0%	$26.38	20.1%	$29.19	18.9%

Source: Transit Economic Requirements Model.

Changes in the Value of Time

The most significant source of transit investment benefits, as assessed by TERM's benefit-cost analysis, is the net cost savings to users of transit services, a key component of which is the value of travel time savings. Therefore, the per-hour value of travel time for transit riders is a key model input and a key driver of total investment benefits for those scenarios that employ TERM's benefit-cost test. Readers interested in learning more about the measurement and use of the value of time for the benefit-cost analyses performed by TERM, Highways Economic Requirements System (HERS), and National Bridge Investment Analysis System (NBIAS) should refer to the related discussion presented earlier in the highway section of this chapter.

For this C&P report, the **Low Growth** and **High Growth Scenarios** are the only scenarios with investment needs estimates that are sensitive to changes in the benefit-cost ratio. (Note: The **Sustain 2010 Spending Scenario** uses TERM's estimated benefit-cost ratios to allocate fixed levels of funding to preferred investments, while the computation of the **SGR Benchmark** does not employ TERM's benefit-cost test in any way.)

Exhibit 10-10 shows the effect of varying the value of time on the needs estimates of the **Low Growth** and **High Growth Scenarios**. The baseline value of time for transit users is currently $12.50 per hour, based on Department of Transportation (DOT) guidance. TERM applies this amount to all in-vehicle travel, but then doubles this amount to $25.00 per hour when accounting for out-of vehicle travel time, including time spent waiting at transit stops and stations.

Given that value of time is a key driver of total investment benefits, changes in this variable lead to changes in investment ranging from an increase of more than 10 percent to a decrease of more than 6 percent. The resulting different magnitudes of percent changes is because the absolute value of the changes from the baseline are different ($6.25 is a 50 percent change from baseline and $25 is a 100 percent change from baseline). In addition to this issue, we observe that the **High Growth Scenario** appears to be more sensitive to the value of time than the **Low Growth Scenario**. This is due to the fact that higher investment levels are associated with the **High Growth Scenario** than with the **Low Growth Scenario**; therefore, any changes in the value of time will be magnified accordingly.

Exhibit 10-10 Impact of Alternative Value of Time Rates on Transit Investment Estimates by Scenario

	Low Growth Scenario		High Growth Scenario	
Changes in Value of Time	**Billions of 2010 Dollars**	**Percent Change From Baseline**	**Billions of 2010 Dollars**	**Percent Change From Baseline**
Reduce 50% ($6.25)	$20.85	-5.1%	$22.98	-6.4%
Baseline ($12.50)	$21.96		$24.54	
Increase 100% ($25.00)	$23.40	6.6%	$27.04	10.2%

Source: Transit Economic Requirements Model.

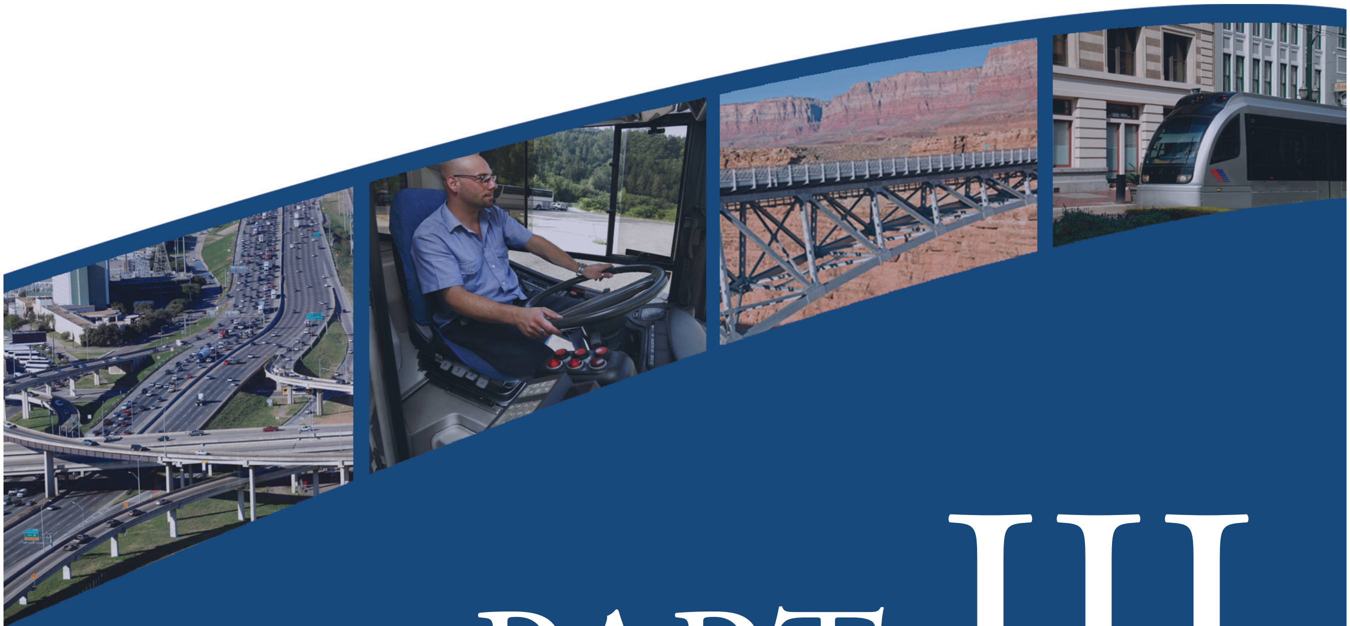
Changes to the Discount Rate

Finally, TERM's benefit-cost module utilizes a discount rate of 7.1 percent in accordance with White House Office of Management and Budget (OMB) guidance. Readers interested in learning more about the selection and use of discount rates for the benefit-cost analyses performed by TERM, HERS, and NBIAS should refer to the related discussion presented earlier in the highway section of this chapter. For this sensitivity analysis and for consistency with the HERS and NBIAS discount rate sensitivity discussion above, TERM's needs estimates for the **Low Growth** and **High Growth Scenarios** were re-estimated using a 3 percent discount rate. The results of this analysis are presented in *Exhibit 10-11*. These results show that this approximately 58 percent reduction in the discount rate yields an increase in total investment needs (or an increase in the proportion of needs passing TERM's benefit-cost test) of 3.2 to 6.1 percent.

Exhibit 10-11 Impact of Alternative Discount Rates on Transit Investment Estimates by Scenario

	Low Growth Scenario		High Growth Scenario	
Discount Rates	**Billions of 2010 Dollars**	**Percent Change From Baseline**	**Billions of 2010 Dollars**	**Percent Change From Baseline**
7.10% (Baseline)	$21.96		$24.54	
3.00%	$22.67	3.2%	$26.03	6.1%

Source: Transit Economic Requirements Model.



PART III

Special Topics

Introduction

Chapters 11 through 13 are intended to provide additional insights into topics touched on elsewhere in this report, and to highlight related issues. Chapter 11 provides information on transportation serving Federal and tribal lands, a subset of the transportation system that is not explored in depth in the analyses presented in Chapters 1 through 10. While the investment analyses presented in Part II of this report focus mainly on the potential impacts of alternative levels of investment on future conditions and performance, it is important to recognize the role that innovation and technology can play in ensuring the efficacy of these investments; for this reason, in Part III, Chapters 12 and 13 explore some activities currently under way within the U.S. Department of Transportation (U.S. DOT) to accelerate innovation and explore new technologies.

Chapter 11, **Transportation Serving Federal and Tribal Lands**, examines the transportation systems serving Federal lands, including resources and types of lands served, and the role of these systems. It also discusses the condition, sources of funding, and expenditures. Lastly, it discusses the future of the transportation systems in Federal lands.

Chapter 12, **Center for Accelerating Innovation**, examines aspects of utilizing innovation to improve the way transportation infrastructure is created and maintained. It includes initiatives under this program and also discusses the benefits generated for the highway system because of the innovative initiatives.

Chapter 13, **National Fuel Cell Bus Program**, discusses the background, accomplishments, and current status of fuel cell transit bus research. It describes fuel cell electric bus research projects in the United States and the impact of these projects on commercialization of fuel cell power systems and electric propulsion for transit buses in general.

CHAPTER 11

Transportation Serving Federal and Tribal Lands

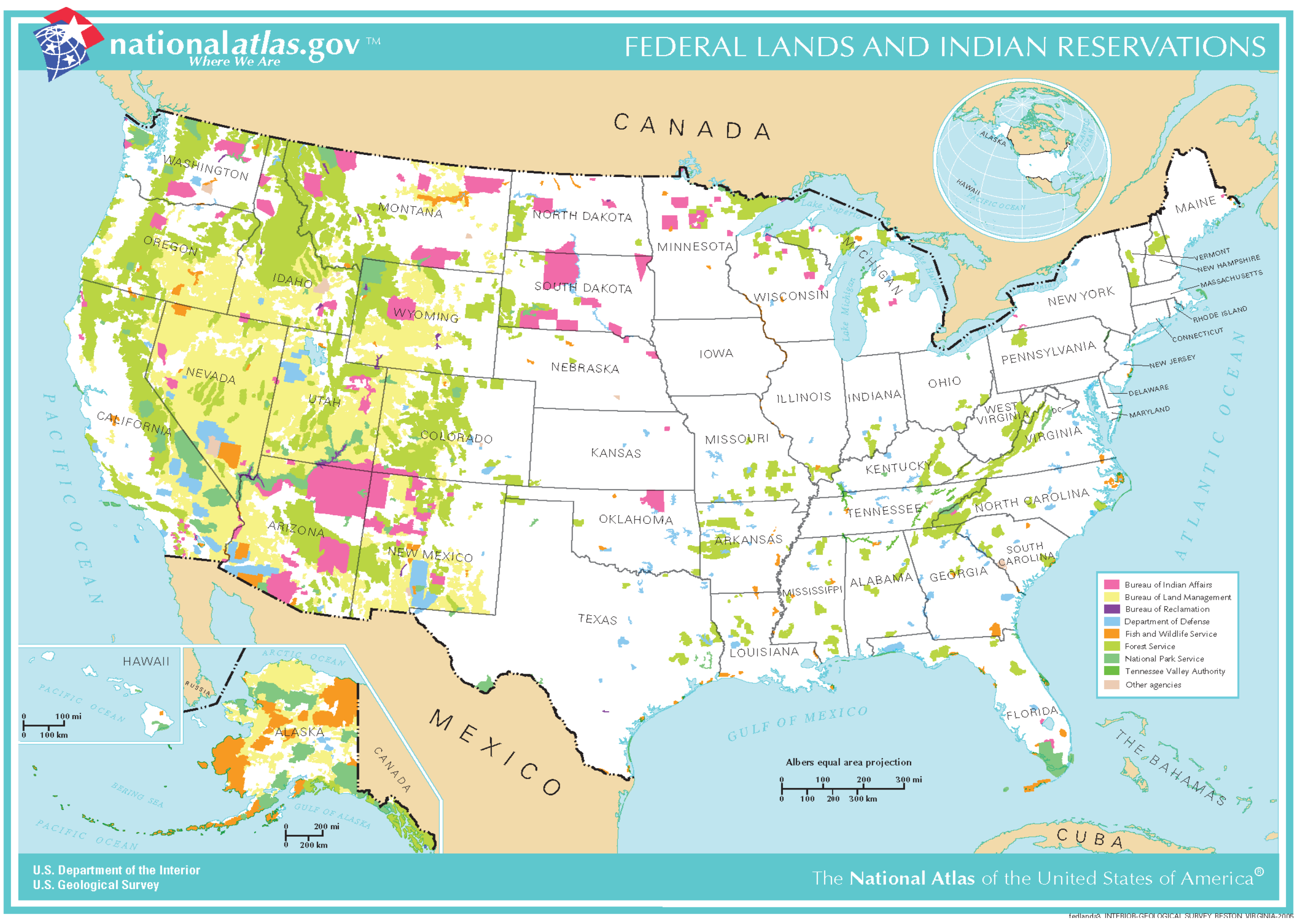
Transportation Serving Federal and Tribal Lands

This chapter documents transportation serving Federal and Tribal lands, a subset of the transportation system that is not explored in depth in the analyses presented in Chapters 1 through 10. Included are discussions of the types of lands, the resources served, the role of Federal and Tribal lands in the U.S. economy, the role of transportation in the use of Federal and Tribal lands, the condition of the transportation system, sources of funding, expenditures of funds for construction and maintenance of transportation infrastructure, and the future of Federal and Tribal transportation.

Types of Federal and Tribal Lands

The Federal government has title to about 650 million acres[1], or about 30 percent of the United States' total area of 2.3 billion acres[2]. Additionally, the Federal government holds in trust approximately 55 million acres of land on behalf of Tribal governments. These lands are primarily located in the western part of the country. Federal lands are managed by various Federal land management agencies (FLMAs), primarily within the Departments of the Interior (DOI), Agriculture (USDA), and Defense (DOD). Tribal lands are primarily held in trust by the DOI's Bureau of Indian Affairs, though many Tribes own additional land beyond these trust lands. *Exhibit 11-1* illustrates the major Federal and Tribal lands (note that this only shows the large

Exhibit 11-1 Major Federal Lands



Source: The National Atlas of the United States of America.

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units; many smaller units are not shown due to the scale of the image). *Exhibit 11-2* highlights resources managed by eight FLMAs.

Exhibit 11-2 Types of Lands Managed by Federal Land Management Agencies

Federal Agency	Federal Lands Served
Department of Agriculture	
Forest Service (FS)	155 National Forests and 20 National Grass Lands
Department of the Interior	
National Park Service (NPS)	401 National Parks and Monuments
Fish and Wildlife Service	556 Wildlife Refuges, 38 Wetland Management Districts, 70 Fish Hatcheries and 43 Administrative sites
Bureau of Land Management	247.5 million acres of public lands; 700 million acres of subsurface mineral estate; 601 recreation sites
Bureau of Indian Affairs	566 federally-recognized Indian Tribes
Bureau of Reclamation	476 dams, 348 reservoirs, 187 recreation areas, and 58 power plants
Department of Defense	
Military Installations	400 Major Military Installations
U.S. Army Corps of Engineers - Civil Works Facilities	423 lakes

Source: FLMAs.

Accessing Tribal Communities

An Indian reservation is land reserved for a Tribe when it relinquished its other land areas to the United States through treaties. More recently, Congressional acts, Executive Orders, and administrative acts have also officially recognized Tribes and their lands. Tribal communities exist in all corners of the country. Some Tribes are located in the cities or suburbs, but most are located in rural America. The 229 Alaska Native Villages continue to be found at their historic locations throughout the State of Alaska. Access to basic community services for the 566 federally recognized sovereign Tribal governments is primarily served by roads, but also can include ice roads, snow machine and ATV trails, airfields, and waterways in remote Alaskan villages. Some Tribes operate transit service within their communities. This transportation infrastructure (roads, bridges, trails, or transit systems) can be owned by the Bureau of Indian Affairs, Tribes, States, counties, or other local governments.

Many roads accessing tribal lands can be characterized as substandard native surface roadways, which can only be used during periods of good weather. Access to many critical community services, jobs, stores, schools, hospitals, emergency services, or intercommunity commerce can be compromised by a common rain event or a thaw of an Alaskan river or permafrost. More than 8 billion vehicle miles are traveled annually on the Tribal Transportation Program road system, even though it is among the most rudimentary of any transportation network in the United States, with more than 60 percent of the system unpaved.

Resources Served within Federal Lands

The natural and cultural resources of Federal and Tribal lands are among the Nation's greatest assets. Each individual site managed by the FLMAs has a unique mission for managing its resources while providing access in varying degrees to those resources for the enjoyment of the public and the citizens living on those lands. Most FLMAs are charged with managing the wise use of resources for the benefit of present and future generations. Resource management includes preserving and protecting natural, cultural, and historical areas as well as wildlife use areas. Many of the sites have multiple uses, while others have a very limited, specific use. It is estimated that approximately one-half of the Federal lands are managed under multiple use and sustained yield policies that rely on transportation. The remaining lands have protected use management

policies, but even so, transportation systems are essential to their resource management, development, recreational use, and protection.

Federal lands have many uses. These include facilitating national defense, recreation, range and grazing, timber and minerals extraction, energy generation, watershed management, fish and wildlife management, and wilderness. These lands are also managed to protect natural, scenic, scientific, and cultural values. In recent years, resource extraction and cutting of timber have been significantly reduced. At the same time, recreation use has significantly increased. *Exhibit 11-3* summarizes annual recreation use and visits on Federal lands. Recreation on Federal lands is measured in recreation visitor days (RVD), which is equivalent to a 12-hour visit.

Exhibit 11-3 Summary of Annual Recreation Use and Visits

Agency	Recreation Visits (Millions)	Recreation Visitor Days (Millions)	# of Sites
Department of Agriculture			
Forest Service	173	288	175
Department of the Interior			
National Park Service	279	101	397
Fish and Wildlife Service	46	46	626
Bureau of Land Management	58	58	601
Bureau of Indian Affairs	N/A	N/A	N/A
Bureau of Reclamation	28	28	187 areas
Department of Defense			
Military Installations	10	53	400+
U.S. Army Corps of Engineers - Civil Works Facilities	365	210	463
Total	**959**	**884**	**2,849+**

Source: FLMAs.

Role of Transportation in the Use of Federal and Tribal Lands

Tribal communities, national defense, recreation, travel and tourism, and resource extraction are all dependent on quality transportation infrastructure. Transportation plays a key role in the way that people access and enjoy Federal and Tribal lands, and in providing access to jobs and resources. It is impossible to conceive of visiting our Federal lands without the hundreds of thousands of miles of Federal and Tribal roads, trails, and transit systems providing access to and within these lands. This transportation infrastructure provides opportunities for employment, recreational travel and tourism, protection and enhancement of resources, sustained economic development in rural/urban areas, access to educational and health services, and national and international access to our Nation's most pristine natural, cultural, and historic resources.

Federal agencies, along with States, have designated numerous highways as Scenic Byways, many of which are Federal roads. The Forest Service began designating National Forest Scenic Byways in 1988; as of 2012, more than 130 routes have been designated, totaling 9,000 miles in 36 States. There are more than 3,000 miles of U.S. National Park Service (NPS) roads and parkways that also meet the criteria for Scenic Byways. In 1989, the Bureau of Land Management (BLM) began designating the Back Country Byways; more than 60 routes have been designated to date, totaling 3,100 miles in 11 States.

Public roads make up significant portions of the transportation systems serving these Federal and Tribal lands. In many areas—both urban and rural—transit, bicycling, and pedestrian use supplement this road network, though most agencies do not track this usage. In many remote areas, motorized and non-motorized trails, waterways, and air transports serve as the primary mode of transportation. The broad range of needs dependent on transportation access to Federal lands is summarized in *Exhibit 11-4*.

Exhibit 11-4 Federal Land Use

Federal Agency	Recreation	Wildlife	Minerals, Oil, & Gas	Grazing & Farming	Water Resources	Timber	Industry	Energy	Housing	National Defense
Department of Agriculture										
Forest Service	X	X	X	X	X	X	X	X	X	X
Department of the Interior										
National Park Service	X	X			X				X	
Fish and Wildlife Service	X	X	X	X	X	X	X	X		
Bureau of Land Management	X	X	X	X	X	X	X	X		
Bureau of Indian Affairs	X	X	X	X	X	X	X	X	X	
Bureau of Reclamation	X	X	X	X	X			X		
Department of Defense										
Military Installations	X	X			X		X		X	X
U.S. Army Corps of Engineers - Civil Works Facilities	X	X	X	X	X	X		X		

Source: FLMAs.

Role of Federal Lands in U.S. Economy

The American outdoor recreation economy produces 6.1 million jobs, spurs $646 billion in spending, and creates $39.9 billion in Federal tax revenue and $39.7 billion in state and local tax revenue.[3] In total, there are nearly 1 billion visits per year to Federal lands. In 2011, the recreational visits to lands owned by the Department of the Interior supported over 403,000 jobs and contributed around $48.7 billion in economic activity[4]. This economic output in 2011 represents about 6.5 percent of the direct output of tourism related personal consumption expenditures for the United States and about 7.6 percent of the direct tourism-related employment. The travel, tourism, and recreation industry claim a share of many other industry sectors, including transportation, lodging, communications, power, wholesale and retail trade, manufacturing, and construction.

Not only is travel and tourism a significant part of our Nation's economy, it is also an integral part of many local economies in communities adjacent to Federal lands. Overall, recreating visitors spend a little more than $11 billion per year in areas around National Forest System lands. In total, spending by visitors to National Forests and Grasslands contributes almost $13.4 billion to the U.S. economy and sustains more than 205,000 full-and part-time jobs[5]. Direct and indirect economic benefits on BLM lands from recreation are $7 billion and contribute a total of nearly 59,000 jobs[6] . The U.S. Fish and Wildlife Service (FWS) reported that visits to units of the National Wildlife Refuge System (NWRS) generated more than $1.7 billion for the economy per year and employ nearly 27,000 people[7]. Nationally, U.S. Army Corps of Engineers lakes attract 365 million recreation visitors every year, and the economic impact on these areas is enormous. The total economic benefits on local communities (within 30 miles of a lake) include more than 112,000 jobs, almost $3 billion in annual salaries and wages, and more than $9.7 billion in total spending. An additional $1.5 billion in spending are generated outside the 30-mile radius resulting in total spending of over $11 billion and supporting 189,000 jobs nationwide. In addition, visitors to Corps lakes also spend $5 billion a year on recreation equipment which supports 81,000 jobs. That is $16 billion a year in spending by Corps lake visitors and 270,000 jobs to the Nation's economy[8].

There are significant amounts of national and international visitation to national parks that add considerably to the gross national product of the United States. The national park units receive approximately 279 million visitors annually. Recreational use in the national parks is expected to double by the year 2020. Park visitors spent $12.13 billion[9] in the local region surrounding the parks. The contribution of this spending to the national economy is 258,400 jobs, $9.8 billion in labor income, and $16.6 billion in value added. *Exhibit 11-5* summarizes recreation-related economic benefits and employment.

In addition to recreation, travel, and tourism, Federal lands provide substantial economic benefit from resource outputs including defense-related industries, grazing, timber harvesting, oil extraction, mining, electrical generation, and related activities. In many instances, a portion of the receipts are returned directly to local governments.

Exhibit 11-5 Economic Benefits of Federal Lands*

Federal Agency	Recreation Related Jobs	Recreation Economic Benefits ($ Billion)
Department of Agriculture		
Forest Service	205,000	13
Department of the Interior		
National Park Service	258,000	39
Fish and Wildlife Service	27,000	2
Bureau of Land Management	59,000	7
Bureau of Reclamation	N/A	N/A
Department of Defense		
Military Installations	N/A	N/A
U.S. Army Corps of Engineers - Civil Works Facilities	270,000	16

** Economic benefits include lodging, food, entertainment, recreation, and incidentals expended during travel.*

Source: FLMAs.

Condition and Performance of Roads Serving Federal and Tribal Lands

While the primary focus of the C&P report is on the Nation's highways, bridges, and transit systems as a whole, the Federal government has a special interest and responsibility for public roads and transportation that provide access to and within federally and tribally owned lands. The transportation systems serving various Federal and Tribal lands are discussed below. Roads serving these lands are summarized in *Exhibit 11-6*.

Exhibit 11-6 Roads Serving Federal Lands

Agency	Public Paved Road Miles	Paved Road Condition			Public Unpaved Road Miles	Public Bridges		Backlog of Deferred Maintenance
		Good	Fair	Poor		Total	Structurally Deficient	
Forest Service	10,700	25%	50%	25%	259,300	3,840	6%	$5.1 billion
National Park Service	5,450	60%	28%	12%	4,100	1,270	3%	$5 billion
Bureau of Land Management	700	60%	20%	20%	2,000	439	3%	$350 million
Fish & Wildlife Service	400	59%	23%	18%	5,200	281	7%	$1 billion
Bureau of Reclamation	762	N/A	N/A	N/A	1,253	311	11%	N/A
Bureau of Indian Affairs	8,800	N/A	N/A	N/A	20,400	929	15%	N/A
Tribal Governments	3,300	N/A	N/A	N/A	10,200	N/A	N/A	N/A
Military Installations	26,000	N/A	N/A	N/A	N/A	1,422	11%	N/A
U.S. Army Corps of Engineers	5,135	55%	25%	20%	N/A	294	11%	$100 million

Source: FLMAs.

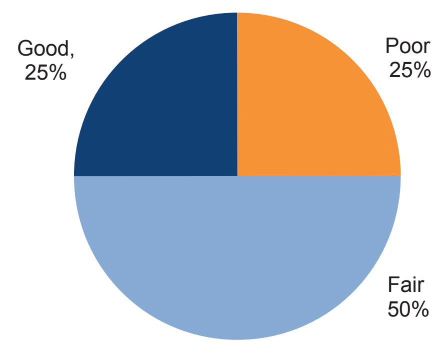
Forest Service

The USDA Forest Service has jurisdiction over the National Forest System (NFS) that contains a total of 155 national forests and 20 grasslands spanning approximately 193 million acres in 40 States plus Puerto Rico and the Virgin Islands. The NFS is about 25 percent of federally owned lands.

There are approximately 372,000 miles of National Forest System Roads (NFSR) under the jurisdiction of the Forest Service serving the NFS. About 308,000 miles of NFSR are managed for high-clearance vehicles. Of the 270,000 miles of NFSR, 65,000 miles open to public travel are designated for passenger car use. Of these 137 (9,126 miles) are byways in the National Forest Scenic Byways Program.

The timber harvest volumes have been reduced by 80 percent since the 1980s. The loss of road maintenance support from the timber sale program, reduced resource project related work, and the increase in recreation use has resulted in significant deterioration of the entire road system. The agency currently has a $5.1 billion backlog of deferred maintenance. Approximately 10,700 miles of these roads are paved, and the remainder are surfaced with gravel. As shown in *Exhibit 11-7*, of the paved roads, 25 percent are in good condition, 50 percent are in fair condition, and 25 percent are in poor condition. There are approximately 3,840 bridges on public NFSRs, 6 percent of which are structurally deficient. (See Chapter 3 for a more extensive discussion of structural deficiencies.)

Exhibit 11-7 Forest Roads Pavement Condition (Paved Roads Only)



Source: USFS.

The 102,000 miles of non-public NFSRs provide access for management and protection of the NFS. These roads are generally maintained for high-clearance vehicles. The backlog of deferred maintenance for these roads is estimated at $4.3 billion. Approximately 100,000 miles of the roads are gravel surface, and the remainder are earth surface. There are approximately 1,000 bridges on non-public NFSRs. Approximately 20 percent of these bridges are structurally deficient.

National Park Service

The NPS system includes more than 84 million acres over 401 national park units, which include National Parks, National Parkways, National Monuments, National Historic Sites, National Military Parks, National Battlefields, National Memorials, National Recreational Areas, National Scenic Waterways, and National Seashores.

Roads continue to be the primary method of access to and within the NPS system. With few exceptions, travel by private vehicle or tour buses are the only means of getting to and moving within the system. As a result, some of the most conspicuous problems in units of the NPS system with high visitation levels stem from an inability to accommodate increasing volumes of traffic, larger vehicles and the spiraling demand for visitor parking.

There are about 10,000 miles of park roads and parkways (PRP). Approximately 5,500 miles are paved. As shown in *Exhibit 11-8*, the condition rankings of paved roads are 60 percent good, 28 percent fair, and 12 percent poor. There are approximately 1,270 bridges and 69 tunnels. Approximately 3 percent of the bridges are structurally deficient—deficient due to deterioration. An additional 23 percent of the bridges are functionally obsolete and are labeled such due to a function of the geometrics of these bridges in relation to the geometrics required by current design standards. The NPS owns a number of historic bridges, which are often functionally obsolete. The annual vehicle miles traveled (VMT) is in excess of 2.4 billion based upon

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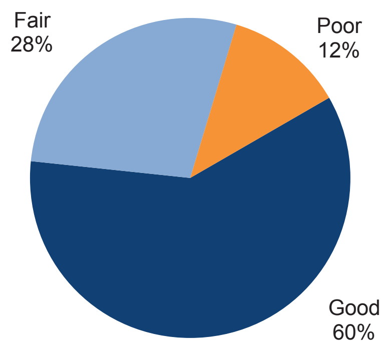
a subset of 33 parks representing 63 percent of paved road miles for which VMT information is available. The number of fatal crashes in the NPS varies between 40 and 60 fatalities per year, with an annual average of 47 fatalities. The average fatal crash rate is less than 2 fatalities per 100 million VMT.

Exhibit 11-8 **Park Roads and Parkways Pavement Condition (Paved Roads Only)**



Source: NPS.

The backlog of improvement needs for paved roads and bridges is more than $5 billion. In addition to this backlog, more than $270 million of new park road construction remains to complete the Natchez Trace Parkway and the Foothills Parkway. Also, there are national parks where congestion has become a major problem and constructing wider or new roadways is not a preferred solution. Investments made in alternative modes of transportation and the integration of several transport alternatives will be key to solving these capacity problems. To address this challenge, the NPS pursues a performance-based strategy, using both analytical tools to maximize investment decisions in terms of pavement, bridge, congestion, and safety metrics, as well as mechanisms that ensure preventive maintenance for those assets.

There are approximately 450 miles of roads intended for non-public use (i.e., roads restricted to official use) which are not funded from the Federal Lands Highway Program (FLHP), but are funded from DOI appropriations. NPS also uses NPS Fee Program dollars and various other funding avenues both public and private to cover the cost to build, operate, and maintain all the different aspects of the NPS transportation system.

The NPS manages 147 discrete transit systems in 72 of the 401 NPS units[10]. These transit systems annually accommodate 36.3 million passenger boardings. Shuttle, bus, van, and tram systems make up the largest share of all system types (44 percent), followed by boat and ferry systems (34 percent), planes (9 percent), snow coaches (10 percent), and trains and trolleys (3 percent). Twenty of these systems are owned and operated by NPS directly and 13 operate under service contracts; together, they account for 13.4 percent of all passenger boardings. A further 97 systems operate under concession contracts and represent the majority (54.4 percent) of all passenger boardings. The final 17 systems operate under a cooperative agreement and represent 18.7 percent of passenger boardings. Fifty-two of these systems provide the sole access to an NPS unit because of resource or management needs and geographic constraints. Twelve systems are operated by a local transit agency under a specific agreement with the NPS. In total, these transit systems include 890 vehicles, including 264 vehicles owned or leased by the NPS, and 56 vehicles which operate in systems with intermixed NPS and non-NPS owners. Two thirds (175 of 264) of the NPS-owned or leased vehicles operate on alternative fuel, while 14 percent (79 of 562) of non-NPS-owned vehicles operate on alternative fuel.

Bicycling and pedestrian usage in the National Parks plays an integral role in the visitor's experience and serves a critical non-motorized transportation function providing access to areas unreachable by motorized travel. Bicycling, hiking, and walking are effective and pleasurable alternatives to motor vehicle travel. NPS is exploring the use of these and other transportation alternatives to disperse visitor use and accommodate more park visitors while alleviating congestion, protecting park resources, and improving the visitor experience. All park trails are open to pedestrians, while 28 percent are paved and used by bicyclists. Bicycle and pedestrian access provides an interface between different transportation modes (i.e., park shuttle and public transportation systems) and many times serves as the primary transportation facility linking visitors (including disabled visitors) with the resources they want to see and experience. The NPS trails inventory includes 17,872 miles of trails, of which 5,012 miles (28 percent) consist solely of front country paved

trails. The total replacement value of these trails is approximately $2.5 billion. The approximate deferred maintenance value is over $315 million. Approximately 21 percent of front country paved trails (1,070 miles) are in fair, poor, or serious condition.

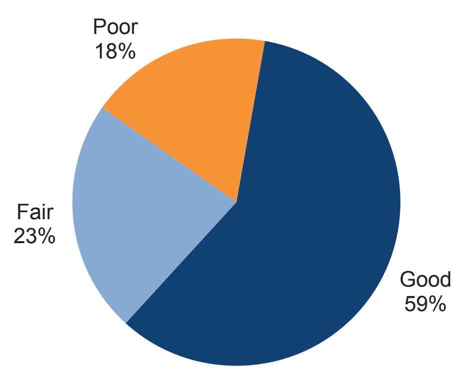
The NPS does not generally track usage of bicycle or pedestrian trails. However, some NPS units track bicycle or pedestrian usage in multi-modal contexts. For example, the Cuyahoga valley Scenic Railroad has served an average of 21,000 "Bike Aboard!" passengers each year since its inception in 2008. Cuyahoga Valley National Park in Ohio partnered with the Cuyahoga Valley Scenic Railroad to offer "Bike Aboard!" so that bicyclists can ride the Towpath Trail and pick up the railroad to return to their starting location. This program offers visitors the flexibility to pedal as far as they want with an option to return by train. It also provides a wonderful opportunity to view the park from two different perspectives. Another example is the 45-mile historic Carriage Path network in Acadia National Park in Maine, a crushed stone aggregate system of paths providing access to pedestrians and non-motorized equipment users (e.g., bicycles, skis) to park resources directly from surrounding towns without the need of a vehicle. In conjunction with the Carriage Path network, the Acadia Island Explorer public transportation system carried nearly 424,000 visitors in 2013. Each bus has the capacity to transport bicycles to points throughout the park to access the Carriage Path network, and a dedicated Bicycle Express route carried over 17,000 riders in 2013 alone. Ridership of this transportation system has increased 77 percent since it started in 2001.

Fish and Wildlife Service

The U.S. Fish and Wildlife Service (FWS) manages the National Wildlife Refuge System (NWRS). This system consists of 594 wildlife refuges and wetland management districts encompassing 150 million acres of land. It receives about 46 million recreation visits per year and has a variety of roads, trails, boat ramps, access points, bicycle trails, viewing areas, etc. The FWS also operates 70 National Fish Hatcheries that are open to the public for visits and tours. The FWS owns more than 11,000 miles of wildlife refuge roads, including 5,600 miles of public roads.

Approximately 400 public miles are paved; the remaining 5,200 miles consist of gravel and native surfaced roads open to the public. The condition of the public-use roads during the 2008–2012 condition assessments were 59 percent excellent to good, 23 percent fair, and 18 percent poor to failed, as shown in *Exhibit 11-9*. There are about 281 bridges and 5,150 parking lots associated with the public road system. Approximately 7 percent of the bridges are structurally deficient.

Exhibit 11-9 Wildlife Refuge Roads Condition



Source: FWS.

The 2008–2012 inventory and condition assessment identified a maintenance backlog that approaches $1 billion for all public roads and bridges. Using estimated life cycles of 10 years for gravel roads and 20 years for paved roads, prorated annual infrastructure replacement costs amount to approximately $100 million a year to maintain the existing system.

The FWS owns and operates 16 permanent transit systems, with temporary service expanded to other units during special events, such as the 3-day Festival of the Cranes at Bosque Del Apache National Wildlife Refuge in New Mexico. A more comprehensive inventory of FWS transit needs will be conducted in FY 2014. Further, at least seven urban transit systems currently serve FWS units. Additionally, the 2013 FWS Urban Refuge Initiative implementation strategy has included as a "standard of excellence" the increase of equitable access to urban refuges by transit and trails for refuges within 25 miles of urban areas with populations greater than 250,000.

Also, pedestrian and bicycle use continue to be important ways for visitors to experience FWS lands. There are nearly a million visits on bicycles on FWS lands and more than 15 million uses of FWS footpaths annually. The FWS maintains 2,187 miles of trails, 95 percent of which are in excellent to good condition. Approximately 32 percent of these miles are paved or boardwalk, and the remainder are gravel, native surface, wood chipped, or mowed. These trails have a current replacement value of $186 million, with a deferred maintenance backlog of $1.3 million, which yields a trails facility condition index of 0.007.

Bureau of Land Management

The BLM manages 16 percent of the surface area of the United States and is the largest manager (40 percent) of Federal lands. The BLM lands, totaling 247.5 million acres, are concentrated primarily in the 11 Western States and Alaska. These lands often make up between 20 to 80 percent of the individual States and/or their political subdivisions. These lands play a significant role in the environmental and socioeconomic fabric of the Nation, its Western States, Alaska, and local governmental units. The BLM also manages 700 million acres of subsurface mineral estate throughout the United States.

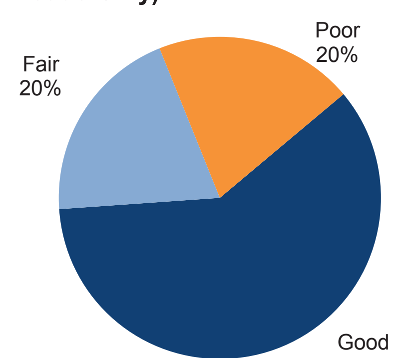
As the National Parks and National Forest have become more overcrowded, an increasing number of people are using facilities on BLM-managed lands. Between 1991 and 2007, visitor use of BLM lands and facilities increased 62 percent.

Comprehensive transportation planning has become a major priority to the BLM. Extensive cross-country travel, which can impact vegetation, soils, air and water quality, and cultural resources, and can fragment habitat on "open" or unrestricted lands, has led the BLM into an era that calls for thoughtful and comprehensive transportation planning. Completing travel plans by inventorying, evaluating, and deciding how roads or areas will be designated is an enormous task. Travel plans on more than 100,000,000 acres still remain to be completed.

The BLM owns approximately 74,000 miles of public lands development roads and trails (PLDR&T), which is the primary road system on BLM lands. The PLDR&T are not considered public roads. However, there are about 2,700 miles of BLM roads being proposed for inclusion in the Federal Land Highway system under Moving Ahead for Progress in the 21st Century (MAP-21) as public roads. Many of the roads serve public uses and special purposes, such as those that serve recreational development areas. The PLDR&T system evolved from a user-established system dating back to the period in which settlement of the West first began. The BLM will soon complete a 10-year effort to inventory and assess the condition of its road system. This effort has identified deferred maintenance and capital replacement costs as well as gathered basic inventory and geospatial data over what is currently considered to be the agency's road system (approximately 49,000 miles). Additionally, the BLM has another set of assets as part of its formal transportation system, known as Primitive Roads. Primitive roads, or high-clearance roads, do not normally meet any BLM road design standards. The BLM has an inventory of approximately 25,000 miles of primitive roads.

The PLDR&T system has approximately 700 miles of paved public roadways. The system has about 439 public bridges and major culverts. As shown in *Exhibit 11-10*, the condition of paved roads is 60 percent good, 20 percent fair, and 20 percent poor. Approximately 3 percent of the public bridges are structurally deficient. The backlog of improvement needs is $350 million.

Exhibit 11-10 **BLM Roads Pavement Condition (Paved Roads Only)**



Source: BLM.

Bureau of Reclamation

The Bureau of Reclamation (Reclamation) administers 476 dams and 348 reservoirs in the 17 Western States and manages in partnership 187 recreation areas. One of the most notable reservoirs is Lake Mead, created by the Hoover Dam. Reclamation is the ninth largest electric utility and second largest producer of hydropower in the United States, with 58 power plants producing on the average 40 billion kilowatt-hours annually. Reclamation is also the Nation's largest wholesale water supplier, delivering 10 trillion gallons of water to more than 31 million people each year and providing one out of five western farmers with irrigation water.

Reclamation owns approximately 2,015 miles of roads that are open for use by the general public, of which 762 miles are paved. Additionally, Reclamation owns 311 public bridges, and approximately 11 percent of the public bridges are structurally deficient. Reclamation also owns administrative roads and operations and maintenance (O&M) roads which are estimated to be approximately 8,000 miles, and are not open to the public.

Bureau of Indian Affairs

The United States has a unique legal and political relationship with Indian tribes and Alaska Native entities as provided by the Constitution of the United States, treaties, court decisions, and Federal statutes. Within the government-to-government relationship, the Bureau of Indian Affairs (BIA) provides services directly or through contracts, grants, or compacts to 566 federally recognized tribes with a service population of about 1.9 million American Indian and Alaska Natives. The BIA offers an extensive scope of programs that covers the entire range of Federal, State, and local government services. Programs administered through the BIA include social services, natural resources management on trust lands representing 55 million surface acres and 57 million acres of subsurface minerals estates, economic development programs in some of the most isolated and economically depressed areas of the United States, law enforcement and detention services, administration of tribal courts, implementation of land and water claim settlements, housing improvement, disaster relief, replacement and repair of schools, repair and maintenance of roads and bridges, and the repair of structural deficiencies on high-hazard dams. The BIA operates a series of irrigation systems and provides electricity to rural parts of Arizona.

The BIA has responsibility over approximately 29,200 miles of existing roads that are open for use by the general public, of which 8,800 miles are paved. Tribal governments further own an additional 13,500 miles of existing public use roads, including 3,300 miles of paved roads. Neither number includes any mileage for future or proposed roads that are in the inventory. Approximately 17 percent of total BIA and tribally owned roads are in acceptable condition. Additionally, the BIA owns 929 public bridges, and approximately 15 percent of the public bridges are structurally deficient. Approximately 68 percent of these bridges are in acceptable condition. The number and condition of tribally owned bridges is currently unknown, since these were first required to be inspected in 2013 with the passage of the Moving Ahead for Progress in the 21st Century Act (MAP-21).

Department of Defense

The mission of the Department of Defense (DOD) is to provide the military forces needed to deter war and to protect the security of our country. The DOD owns millions of acres of land within the continental United States. There are more than 400 major military installations in the United States, encompassing about 20 million acres of land, which are integral to the defense of the country. The economic benefit provided by the DOD to the country as a whole has not been precisely calculated, but is in the hundreds of billions of dollars.

When one thinks of DOD installations, one assumes that they are generally not open to the public due to the overriding military mission of those specific areas. However, many installation roads are open to use by dependents, visitors, and other members of the public, even though there may be a requirement to stop at a gate area. Roads on military installations serve housing offices, commissaries, base exchanges, recreation facilities, unrestricted training facilities, hospitals, and traffic crossing the installation. This public street system is similar to the street system in urban areas. In many cases, the military streets are an integral part of the street system of the local community.

The 2008 calculations indicated that the DOD has in excess of 26,000 miles of paved roads under its jurisdiction deemed open for public travel. Travel on installation roads consists of military personnel and their dependents, civilian work force on military installations, contractors performing work for the military, civilian personnel operating businesses, and visitors (to include non-military associated sportsmen). The DOD has 1,422 public bridges, of which 11 percent are structurally deficient.

The DOD maintenance and construction of roadways are prioritized at the local installation level. As the mission of each installation may be extremely different from one installation to another, the infrastructure needs from one installation to another will vary greatly. Therefore, the DOD does not track roadway condition for all installations in any one central repository. That tracking is done at the local level and will continue to remain there. Currently, the DOD does record and document to the FHWA the condition and performance of all bridge structures. This philosophy is consistent in all aspects from geometrics to sign standards. It is DOD policy to adhere, whenever possible, to the same standards non-DOD public roadways are held. For instance, DOD policy is that all DOD roadways are subject to the Manual of Uniform Traffic Control Devices (MUTCD) and should be operated in conformance to MUTCD standards. It is the local installation's responsibility to maintain sign inventories and monitor their programs. This philosophy is in part tied to how installation roadways receive funding for roads. Roadway projects are prioritized and funded with all other military construction work, i.e. barracks, offices, training sites. The DOD does collect State and Federal gas taxes on all military installation service stations but does not retain those funds. In 2011, those sales included more than 468 million gallons of gasoline and more than 5 million gallons of diesel fuel. These sales were to DOD civilians and military personnel who in general live and shop outside military installations.

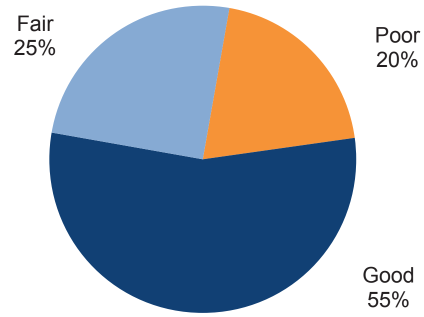
Additionally, in the past 20 years, residences of military personnel have shifted from on-base facilities to off-base housing. This trend has placed a greater emphasis on the need for alternative transportation. Many installations across the country have partnered with adjacent communities to incorporate local transit services onto the installation. For example, Scott Air Force Base is directly served by the St Louis area metro rail and is serviced on base by a bus service operated by the regional transit service. Other installations have implemented similar programs and are implementing transit options where feasible. In addition, the DOD discourages single occupancy vehicle usage by restricting parking and offering special parking for carpooling.

United States Army Corps of Engineers

The United States Army Corps of Engineers (USACE) has the responsibility to maintain and improve navigable waterways throughout the United States, and to mitigate flooding risks affecting the country. One supplementary benefit to the public of the USACE's navigation and flood protection projects is that the USACE has become the largest provider of water-based recreation in the country. The USACE currently administers approximately 12.8 million acres of land and water at 423 lakes and waterways reporting public recreation use throughout the United States.

There are more than 8,800 miles of public roads serving USACE lakes and waterways. About 6,234 miles are owned by the USACE. More than 5,135 miles are paved. The USACE also own 294 public bridges, of which 11 percent are structurally deficient. As shown in *Exhibit 11-11*, the condition of USACE roads are 55 percent Good, 25 percent Fair, and 20 percent Poor. The backlog of improvement needs of public roads and bridges is estimated at $100 million.

Exhibit 11-11 U.S. Army Corps of Engineers Road Condition



Source: USACE.

Transportation Funding for Federal and Tribal Lands

Providing access within Federal and Tribal lands is generally not a State or local responsibility, but Federal government responsibility. Before the 1980s, all road improvements were dependent upon the unpredictability of the various annual Federal Agency appropriations competing with non-transportation needs. This caused many road systems on Federal and Tribal lands to fall into disrepair. The Surface Transportation Assistance Act of 1982 (STAA) established the Federal Lands Highway Program (FLHP). It brought together for the first time a consolidated and coordinated long-range program funded under the Highway Trust Fund.

The funding for FLHP continued and, under SAFETEA-LU, the FLHP provided funding for the NPS's Park Roads and Parkways (PRP), the Bureau of Indian Affair's Indian Reservation Roads (IRR), the FWS's Refuge Roads (RR), and two components of the Public Lands Highway Program: Forest Highways (FH) and a discretionary component called the Public Lands Highway Discretionary Program (PLHD). The funding categories and annual authorizations are shown for FY 1983 through FY 2012 in *Exhibit 11-12*.

On July 6, 2012, the President signed MAP-21 into law. This transformative law realigned and expanded the component programs of the FLHP into three more comprehensive Federal Lands and Tribal Transportation Programs (FLTTP), funded at a total of $1 billion annually for FY 2013 and 2014. The Tribal Transportation Program (TTP), funded at $450 million annually for FY 2013 and 2014, replaces the IRR program. The Federal Lands Transportation Program (FLTP), funded at $300 million annually for FY 2013 and 2014, merges the PRP and RR programs and expands to include transportation facilities owned by the Bureau of Land Management, the U.S. Army Corps of Engineers, and the USDA Forest Service to address improvements to transportation facilities owned by the biggest Federal recreation providers. The Federal Lands Access Program (FLAP) is funded at $250 million annually for FY 2013 and 2014, takes attributes from the FH and PLHD programs to comprehensively address transportation needs on non-Federal roads which provide access to all types of Federal lands.

The FLHP and FLTTP funds may be used for transportation planning, research engineering, and construction of roadways. They may also be used to fund transit facilities that provide access to or within Federal and Tribal lands. Maintenance, rehabilitation, and reconstruction of transportation facilities may also be funded through various other FLMA appropriations.

Exhibit 11-12 FLHP Annual Authorizations ($M)

Authorization	FY	FH	PLHD	IRR	PRP	RR	Total
				Program			
STAA	1983	50	50	75	75	0	**250**
	1984	50	50	100	100	0	**300**
	1985	50	50	100	100	0	**300**
	1986	50	50	100	100	0	**300**
STURAA	1987	55	40	80	60	0	**235**
	1988	55	40	80	60	0	**235**
	1989	55	40	80	60	0	**235**
	1990	55	40	80	60	0	**235**
	1991	55	40	80	60	0	**235**
ISTEA	1992	94	49	159	69	0	**371**
	1993	113	58	191	83	0	**445**
	1994	113	58	191	83	0	**445**
	1995	113	58	191	83	0	**445**
	1996	114	58	191	84	0	**447**
	1997	114	58	191	84	0	**447**
TEA-21	1998	129	67	225	115	0	**536**
	1999	162	84	275	165	20	**706**
	2000	162	84	275	165	20	**706**
	2001	162	84	275	165	20	**706**
	2002	162	84	275	165	20	**706**
	2003	162	84	275	165	20	**706**
TEA-21 Extension	2004	162	84	275	165	20	**706**
SAFETEA-LU	2005	172	88	314	180	29	**783**
	2006	185	95	344	195	29	**848**
	2007	185	95	384	210	29	**903**
	2008	191	99	424	225	29	**968**
	2009	198	102	464	240	29	**1,033**
SAFETEA-LU Extension	2010	198	102	464	240	29	**1,033**
	2011	198	102	464	240	29	**1,033**
	2012	198	102	464	240	29	**1,033**
	Total	**3,762**	**2,095**	**7,086**	**4,036**	**352**	**17,331**

Source: FLHP.

Increasing Walking, Biking, and Transit Use on Federal and Tribal Lands

Growth in public use of Federal and Tribal lands has created a need for additional investment in transportation facilities for transit, bicycle, and pedestrian uses on Federal and Tribal lands. High visitation levels, in both large and small sites, are causing problems due to the growing volumes of traffic and demands for visitor parking. In many areas, it is not that there are too many people but too many motor vehicles and too many visits concentrated in certain time periods. Specific examples of parks that have made successful investments in transit are shuttle bus systems in Denali National Park and Preserve, Acadia National Park, Cape Cod National Seashore, Zion National Park, and Grand Canyon National Park; the train system serving Cuyahoga National Park; and the ferry system serving Fire Island National Seashore.

A 2004 U.S. DOT study estimated transit needs on USDA Forest Service lands. This study identified 30 sites that would benefit from new or supplemental transit investments and estimated that approximately $698 million in 2003 dollars ($714 million in 2004 dollars or $60 million per year) would be needed in these areas between 2003 and 2022. An earlier joint FTA/FHWA study, undertaken in 2001, estimated transit investment needs on NPS, BLM, and FWS lands, which are all part of the DOI. Total DOI needs for the period 2002 to 2020 were estimated to be $1.71 billion in 1999 dollars ($2.16 billion in 2004 dollars or $180 million per year). Ninety-one percent of these needs were estimated to be required by the NPS, 7 percent by the FWS, and 2 percent by the BLM.

In 2005, the Paul S. Sarbanes Transit in the Parks (TRIP) Program was established under the SAFETEA-LU, and provided approximately $26 million of federal funding annually. The TRIP Program was established to help develop new alternatives for enjoying our parks and public lands while protecting resources. The program funded transportation in the parks and public lands; helped conserve natural, historical, and cultural resources; reduced congestion and pollution; improved visitor mobility and accessibility; enhanced the visitors' experience; and helped to ensure access to all, including persons with disabilities. The TRIP Program was not continued under the most recent surface transportation authorization, MAP-21.

Also in 2005, the SAFETEA-LU created the Tribal Transit Program. The SAFETEA-LU authorized funding for this program beginning in FY 2006 at $8 million, increasing to $10 million in FY 2007, to $12 million in FY 2008, and to $15 million in FY 2009 through FY 2012. The MAP-21 increased the funding to $30 million in FY 2013 and 2014. Federally recognized Tribes may use the funding for capital, operating, planning, and administrative expenses for public transit projects that meet the growing needs of rural Tribal communities. Examples of eligible activities include: capital projects; operating costs of equipment and facilities for use in public transportation; and the acquisition of public transportation services, including service agreements with private providers of public transportation services.

The Future of Transportation on Federal and Tribal Lands

In looking at the future transportation needs on Federal and Tribal lands, FLMAs need to address challenges in identifying and involving all of the stakeholders and gaining a better understanding of the complex relationship among these entities. Along with this, the following significant issues continually need to be addressed:

1. As population increases, the demand for access to Federal and Tribal lands will continue to grow. This will require the need to fully consider and implement innovative transportation solutions, including efficient intermodal transfers among the available modes of transportation (pedestrians, bicycles, cars, buses, RVs, transit, ferries, or aircraft). Intelligent transportation systems will continue to play more and more important roles as a way to communicate congestion and provide information on alternative routes and times to visit Federal and Tribal lands.

2. In many instances, urban growth is expanding closer and closer to Federal and Tribal lands. As these lands become part of urban areas, FLMAs and Tribes are challenged with all the issues affecting urban transportation officials. These agencies need to undertake and implement effective urban transportation planning in close cooperation with metropolitan transportation officials, local officials, and various transportation officials. Tribes and FLMAs are focusing on intermodal solutions to challenges of increasing demands for access and balancing those desires with impacts on natural, cultural, and historic resources; and the environment, including air and water quality.

3. As transportation funding continues to lag behind transportation needs, there is a need to ensure more effective coordination between Federal agencies, Tribal governments, and State/local transportation agencies. It also necessitates effective development and implementation of transportation investment that

fully uses products of transportation planning and bridge, safety, pavement, and congestion management systems.

4. The average age of drivers on Federal and Tribal lands will continue to increase. This requires continued improvements in signs, information systems, and accommodation for visitors with disabilities. This will be especially important in urban areas where the need for effective destination guidance is a challenge to implement.

Endnotes

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[2] "Public Land Statistics 2011", Bureau of Land Management, Department of Interior, May 2012. http://www.blm.gov/public_land_statistics/pls11/pls2011.pdf

[3] "The Outdoor Recreation Economy", Outdoor Industry Association, 2012. http://www.outdoorindustry.org/images/researchfiles/OIA_OutdoorRecEconomyReport2012.pdf?167

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CHAPTER 12

Center for Accelerating Innovation

Center for Accelerating Innovation

America's transportation system faces unprecedented challenges. Aging roads and bridges that carry greater traffic volumes and heavier loads than ever need extensive rehabilitation. Limited resources—both staff and budgets—at transportation agencies across the country create the need to work more efficiently and focus on technologies and processes that produce the best results.

At the same time, Americans continue to expect a multimodal transportation system that is safe, accessible, reliable, and convenient. They want to experience a minimum of traffic congestion, whether they are going about their daily lives in their communities or traveling across the country. They also want accountability for the tax dollars that support the building, maintenance, and repair of roads and bridges.

Addressing these challenges requires the transportation industry to pursue ways of doing business that are better, faster, and smarter. It requires harnessing the power of innovation to dramatically change the way highways are built. The FHWA Center for Accelerating Innovation, established in 2011, provides national leadership on deploying innovation to meet today's transportation challenges. The center houses Every Day Counts—an initiative launched in 2009 by FHWA to shorten project delivery, enhance roadway safety, and protect the environment—and Highways for LIFE—the agency's initiative to build roads and bridges faster, better, more safely, and with less impact on the traveling public.

This chapter discusses the goals of the Center for Accelerating Innovation initiatives and the benefits they generate for America's highway system. It also highlights the progress of the initiatives between 2005 and 2012 in helping the highway community use innovation to improve the way the transportation infrastructure is built.

Accelerating Project Delivery in MAP-21

The Moving Ahead for Progress in the 21st Century Act builds on the Every Day Counts initiative with provisions designed to speed up the project delivery process several ways:

- It encourages the use of innovative technologies and practices and enhances contracting efficiencies.
- It targets the environmental review process, providing for earlier coordination, promoting greater linkage between the planning and environmental review process, using a programmatic approach where possible, and consolidating environmental documents. Projects stalled in the environmental review process can get technical assistance to speed their completion.
- It strives to improve project delivery efficiency by broadening States' ability to acquire or preserve right-of-way for a transportation facility before completion of the review process required under the National Environmental Policy Act.

Highways for LIFE: Improving the American Driving Experience

Highways for LIFE, a pilot program established in 2005 by the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, has three goals: improve safety during and after construction, reduce congestion caused by construction, and improve the quality of highway infrastructure. To achieve these goals the program focuses on using sophisticated marketing approaches and dedicated teams to deploy innovations faster and more effectively; it gives highway agencies incentives to use innovations and customer-focused performance goals to build highways better; and it helps industry move promising innovations from the prototype to the market-ready stage, where they can benefit the traveling public.

Through the Highways for LIFE Vanguard Technologies effort, FHWA developed a model technology deployment process that combines multidisciplinary teams, marketing techniques, and focused effort to move innovations all the way to full implementation. The process is designed to deploy technology quickly and efficiently so that years don't elapse between the time that research is done and the time that highway users benefit from an innovation. FHWA also created a training program (Leap Not Creep: Accelerating Innovation Implementation) and a guide to developing marketing plans (FHWA's Guide to Creating an Effective Marketing Plan) that organizations are using to launch their own innovation deployment efforts.

Highways for LIFE helps highway agencies try new approaches by offering financial incentives for construction projects that employ proven but little-used innovations. From fiscal years 2006 to 2012, the program provided incentives totaling about $65 million for 70 projects in 35 States, the District of Columbia, and Puerto Rico. These projects featured innovations such as accelerated bridge construction techniques, precast concrete pavement systems, and new contracting methods. Many projects include showcases to draw transportation professionals from around the country to view innovations in person and learn from their peers what it takes to deploy them.

To qualify for incentive funding, highway agencies had to set project performance goals by defining desired results for safety, speed of construction, mobility, quality, and user satisfaction, and committing to measuring their success in meeting those goals. A change from the traditional practice of specifying how a project should be built, performance goals spur agencies and contractors to use creativity and flexibility in developing solutions to meet project goals and challenges. By documenting and comparing project results to the performance goals set, agencies get data on which to base future decisions.

Recognizing that the private sector is a reservoir of innovation that can benefit the highway system, FHWA developed the Technology Partnerships Program to move useful innovations into routine practice. The program offers grants to help industry turn promising prototypes into market-ready products and fosters partnerships with highway agencies to demonstrate the technologies under real-world conditions. FHWA has funded eight Technology Partnerships projects with grants ranging from $200,000 to $500,000 for a total of nearly $2.8 million. It also launched a program to provide independent evaluation of worthwhile safety technologies with limited U.S. use.

Through Highways for LIFE, the highway community has begun to harness the power of innovation by deploying available technologies with immediate, tangible benefits. As a result, highway community stakeholders are adopting a customer-focused performance model and making innovations that enhance the highway system standard practice. They are changing the way the Nation builds highways to improve the American driving experience.

Every Day Counts: Creating a Sense of Urgency

The Every Day Counts Initiative was launched by FHWA in 2009 to identify and deploy market-ready innovations aimed at speeding up project delivery, making roads safer, and protecting the environment. The idea behind the initiative is to create a new sense of urgency in pursuing better, faster, and smarter ways to build highway infrastructure.

Working on the premise that technology deployment needs to occur much more rapidly to meet today's transportation needs, FHWA created a State-based model in which FHWA teams work with State departments of transportation (DOTs) and other highway community stakeholders to make innovations standard practice. Every Day Counts focuses on high-priority initiatives to accelerate technology and innovation deployment and open highway projects to the public faster. From that menu of technologies, tactics, and techniques, each State chooses the options that work best for its highway program. FHWA

teams work closely with the States to mainstream their selected initiatives over a 2-year period and develop performance measures to gauge their success.

Every Day Counts focuses on two key components:

- **Accelerating technology and innovation deployment.** This category involves identifying market-ready technologies that can benefit the highway system and accelerating their widespread use. This effort is aimed at advancing solutions that enhance safety, reduce congestion, and keep America moving and competitive.
- **Shortening project delivery.** To help the highway community deliver projects faster, FHWA developed a toolkit of strategies for using flexibilities available under current law and eliminating duplicate efforts in the planning and environmental review process. The agency is also recommending innovative contracting practices that accelerate project delivery as standard business practices.

In choosing candidates for the first round of Every Day Counts initiatives that began in October 2010, FHWA sought input from stakeholders throughout the highway community, including industry experts, the American Association of State Highway and Transportation Officials (AASHTO), the American Road and Transportation Builders Association, and the Associated General Contractors of America. Through this collaborative process, FHWA designated five initiatives to focus on in the accelerating technology and innovation category and 10 in the shortening project delivery category (*Exhibit 12-1*). FHWA identified agency experts to champion each initiative and assembled deployment teams.

Working with AASHTO, FHWA advanced the Every Day Counts program nationwide through a series of regional summits in the autumn of 2010. FHWA invited Federal, State, and local agency representatives, industry leaders, and technical experts with direct involvement in delivering Federal-Aid Highway Program projects to participate.

After the summits, each State formed a State Transportation Innovation Council to provide leadership for its Every Day Counts effort. States selected a minimum of five initiatives to pursue over a 2-year period and developed action plans. Many chose to incorporate all of the initiatives into their Every Day Counts effort. This State-based approach recognizes that DOTs serve as the innovation leaders for their States and, by partnering with local and county agencies and industry stakeholders, they can play a key role in innovation deployment.

Exhibit 12-1 Selected Every Day Counts Initiatives

Accelerating Technology and Innovation Deployment

- Adaptive Signal Control Technology
- Geosynthetic Reinforced Soil Integrated Bridge Systems
- Prefabricated Bridge Elements and Systems
- Safety Edge[SM]
- Warm-Mix Asphalt

Shortening Project Delivery Toolkit

- Eliminate Time-Consuming Duplication Efforts
- Encourage Use of Existing Regulatory Flexibilities

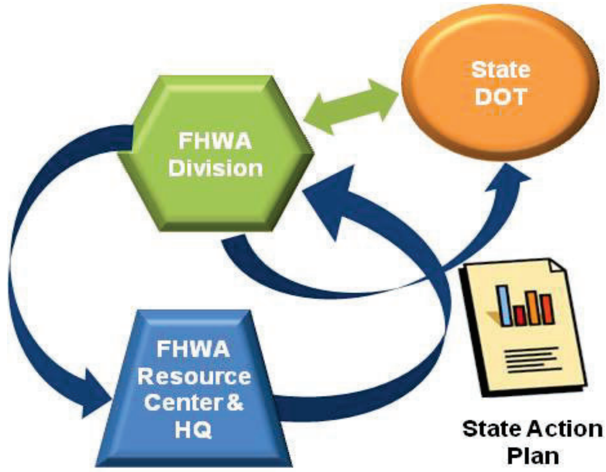
Accelerated Project Delivery Methods

- Design-Build
- Construction Manager–General Contractor

On an ongoing basis, FHWA staff support the State DOTs by offering recommendations on maximizing the effectiveness of Every Day Counts activities. FHWA also provides training and guidance to help State DOTs achieve the goals they set in their action plans (*Exhibit 12-2*). For example, the team focusing on accelerating project delivery conducted regional peer exchanges on the construction manager–general contractor (CM-GC) and design-build initiatives. At each, participants from several States heard perspectives and best practices from DOTs with experience using the contracting approaches, examined case studies, and participated in group exercises. FHWA also uses Web conferences to expedite dissemination of information on technology initiatives. Target audiences include staff from State, regional, and local transportation agencies and the contracting industry.

As well as being rapidly deployable, the initiatives are performance based and measurable. Accountability is inherent to the process of pursuing better, faster, and smarter ways of doing business. As steward of the Nation's transportation system, FHWA is responsible for delivering products and services that engender public trust. The performance goals FHWA set for each initiative help the agency track its progress. All of the initiatives are moving forward as teams implement them across the country. The following sections take a closer look at how several are succeeding in making innovative technologies and construction methods standard practice and shortening project delivery.

Exhibit 12-2 **Every Day Counts State-Based Structure**



Every Day Counts Highlights

In its first 2 years, the Every Day Counts initiative helped States deploy innovations that benefit road users nationwide:

- Forty-three States used the Safety Edge℠ on a paving project.
- Forty-five States are in various stages of implementing warm-mix asphalt.
- Adaptive signal control technology is being installed at 64 project locations.
- A total of 675 replacement bridges were designed or constructed using prefabricated bridge elements and systems (PBES).
- Eighty-five geosynthetic reinforced soil integrated bridge system (GRS-IBS) bridges were designed or constructed.
- Thirteen States have active mitigation banking agreements.
- Fifty-six programmatic agreements were initiated and 101 were updated.
- More than 220 projects were designed and constructed using the design-build (DB) and construction manager-general contractor (CM-GC) project delivery methods.

Accelerating Technology and Innovation Deployment

Accelerating technology and innovation deployment is about taking effective, proven, and market-ready technologies and putting them into widespread use. FHWA is working with State, local, and industry partners to implement the following technologies to improve safety, reduce congestion, and keep people and goods moving.

Safety Edge℠. Pavement edge drop-off on highways has been linked to many serious crashes and fatalities. Rather than leave a vertical drop-off at the pavement shoulder, the Safety Edge shapes the edge of the pavement to a 30-degree angle, making it easier for drivers to steer back onto the roadway for drivers who stray off the travel lane (see Safety Edge discussion in Chapter 4).

The Safety Edge is installed during paving, using a commercially available shoe that attaches to existing paving equipment in just a few minutes. The Safety Edge also decreases pavement edge raveling and contributes to longer pavement life. The benefits of Safety Edge have encouraged 34 State DOTs and all three Federal Lands Highway Divisions to adopt the Safety Edge as a standard for paving projects.

Safety Edge

The Iowa Department of Transportation (DOT) has made the Safety Edge a standard practice, and requires it on all projects with a paved shoulder less than 4 feet wide. In addition to using it on asphalt paving projects, the Iowa DOT was the first in the country to try it on a Portland cement concrete paving project.

Warm-mix asphalt (WMA). Composed in various fashions, WMA enables construction crews to produce and place asphalt on a road at lower temperatures than possible using conventional hot-mix methods. In most cases, the lower temperatures result in significant cost savings because fuel consumption during WMA production is typically 20 percent lower. WMA production also generates fewer emissions, making conditions for workers healthier, and has the potential to extend the construction season, enabling agencies to deliver projects faster.

By July 2012, 45 State DOTs and all three Federal Lands Highway Divisions had adopted a standard specification for WMA use. Twenty-four State DOTs and Federal Lands Highway Divisions had set usage goals ranging from 46,000 to 600,000 tons of WMA per year, or 20 percent to 50 percent of all applicable projects. In 2010, more than 47 million tons of WMA were produced nationwide, a nearly 150-percent increase over 2009. That saved more than 30 million gallons of fuel worth more than $80 million and removed 800,000 tons of CO_2 from the air, which equates to taking more than 150,000 cars off the road.

According to the National Asphalt Paving Association, current data indicate that WMA will capture more than 25 percent of the market in the next year and will be the industry standard for asphalt mixtures in 3 to 5 years.

Warm-Mix Asphalt

The New Hampshire DOT placed about 243,000 tons of WMA in 2011, 41 percent of all pavement the State placed during the year. The Delaware DOT used WMA on about 40 percent of its paving projects in 2011 and plans to use it on all projects by 2015. In Puerto Rico, more than 60,000 tons of WMA were placed on three 2012 projects, resulting in a 30-percent reduction in fuel costs. (Source: Federal Highway Administration, The Best of EDC, May 2012, www.fhwa.dot.gov/everydaycounts/pdfs/bestofedc.pdf.)

Geosynthetic reinforced soil integrated bridge system (GRS-IBS). While utilizing traditional equipment and materials, GRS-IBS uses alternating layers of compacted granular fill material and fabric sheets of geotextile reinforcement to provide support. The technology is particularly advantageous in the construction of small bridges (less than 140 feet long), reducing construction time and generating cost savings of 25 to 60 percent compared to conventional construction methods. It facilitates design flexibility conducive to construction under variable site conditions, including soil type, weather, utilities and other obstructions, and proximity to existing structures.

From October 2010 to July 2012, 85 bridges across the country were designed or built using GRS-IBS. Thirty-seven State DOTs and Federal Lands Highway Divisions are implementing GRS-IBS.

GRS-IBS

Defiance County, OH, used GRS-IBS to build a bridge in just 6 weeks, compared to the months required for traditional construction methods.[1] The county saved nearly 25 percent on the project, not only because of the reduced labor costs resulting from shorter construction time and simpler construction, but also because fewer materials were required for the GRS bridge abutments. GRS-IBS technology helped Clearfield County, PA, build a bridge on a school bus route in just 35 days, saving months of time and 50 percent on costs.[2] Another bridge built using GRS-IBS technology in St. Lawrence County, NY, realized a 60-percent cost savings.[3]

[1] Federal Highway Administration, Every Day Counts, GRS-IBS Case Studies, www.fhwa.dot.gov/everydaycounts/technology/grs_ibs/casestudies.cfm.

[2] Randy Albert, Pennsylvania Department of Transportation, “Every Day Counts,” EDC Forum, www.fhwa.dot.gov/everydaycounts/forum/post.cfm?id=27

[3] Federal Highway Administration, Every Day Counts, GRS-IBS Case Studies, www.fhwa.dot.gov/everydaycounts/technology/grs_ibs/casestudies.cfm.

Adaptive signal control technology. These technologies coordinate the control of traffic signals across a network by adjusting the lengths of signal phases based on prevailing traffic conditions. This improves travel time reliability, reduces congestion, and creates smoother traffic flow.

According to the Information Technology and Innovation Foundation's 2010 report titled Explaining International IT Application Leadership: Intelligent Transportation Systems, applying real-time traffic data to traffic signals can cut red-light delays by as much as 40 percent, CO_2 emissions by 22 percent, and gas consumption by 10 percent. Although adaptive signal control technology has been used in the United States for about 20 years, it had been deployed on less than 1 percent of the Nation's 260,000 traffic signals before its adoption as an Every Day Counts technology in October 2010. By July 2012, 44 State DOTs were implementing the technology.

Adaptive Signal Control Technology

Topeka, KS, installed new traffic signals equipped with cameras and processors on the 21st Street corridor. The system saves drivers on the corridor an estimated 123,000 gallons of gasoline and 191,000 pounds of CO_2 a year. Crashes dropped by 30 percent during the system's first year of operation.[1] The city of Temecula, CA, deployed the technology at 83 intersections spanning 18 miles of roadway. As a result, drivers have enjoyed a 14 percent reduction in travel time, a 17 percent increase in corridor speed, and a 29 percent reduction in stops. That translates to annual savings of about $2.6 million in travel time and $437,000 in fuel costs.[2]

[1] Federal Highway Administration, The Best of EDC, May 2012, www.fhwa.dot.gov/everydaycounts/pdfs/bestofedc.pdf.

[2] Federal Highway Administration, Every Day Counts, Adaptive Signal Control Case Studies, www.fhwa.dot.gov/everydaycounts/technology/adsc/casestudies.cfm.

Prefabricated bridge elements and systems (PBES). With PBES, prefabricated components are constructed off-site and moved to the work zone for rapid installation, reducing the level of traffic disruption typically associated with bridge replacement. In some cases, PBES makes it possible to remove the old bridge overnight while putting the new bridge in place the next day. Because PBES components are usually fabricated under controlled conditions, weather has less impact on the quality and duration of the project.

Forty-seven State DOTs and Federal Lands Highway Divisions are implementing PBES as part of Every Day Counts. Between October 2010 and July 2012, 675 replacement bridges were designed or constructed using PBES. About 18 percent of all replacement bridges using Federal-aid funds have at least one major prefabricated bridge element.

Prefabricated Bridge Elements and Systems

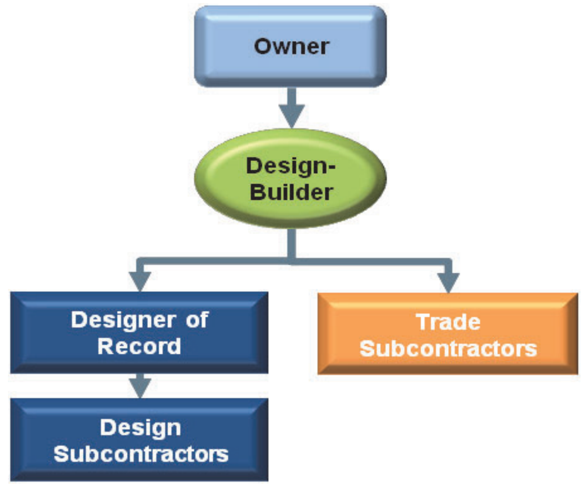
The Massachusetts DOT used prefabricated bridge elements on a project to replace 14 bridge superstructures on I-93 in Medford, shrinking a 4-year bridge replacement project to just one summer. The agency built the bridge superstructures in sections off-site and installed them on weekends during 55-hour windows to minimize impact on travelers.

Accelerating Project Delivery Methods

The sooner highway agencies can complete major projects, the sooner the public can begin enjoying their benefits. With the traditional design-bid-build (DBB) construction method, highway projects can take years to deliver. The accelerated project delivery method initiative is aimed at reducing the time it takes to complete highway projects by as much as 50 percent. Every Day Counts is focusing on two innovative contracting methods that can trim years from project schedules and is encouraging State DOTs to adopt them as standard business practices.

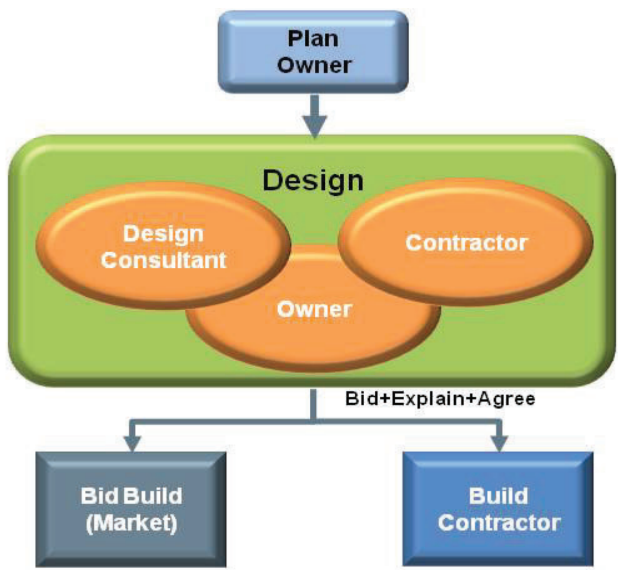
Design-build contracting. Design-build (DB) is a project delivery method in which the design and construction phases are combined into one contract, allowing some aspects of design and construction to take place at the same time (*Exhibit 12-3*). This approach can provide significant time savings compared to the traditional DBB approach, in which the design and construction phases take place sequentially. The designer-builder assumes responsibility for most of the design work and all construction activities. Along with greater responsibility and risk, DB allows the designer-builder more flexibility to innovate. Twenty-eight DOTs and all three Federal Lands Highway Divisions are implementing the initiative, and DB was used on about 200 projects from 2010 to 2012. Twenty-four States expanded their DB statutory authority in 2011 and 2012, according to the Design-Build Institute of America.

Exhibit 12-3 Design-Build Process



Construction manager–general contractor. Another alternative to the traditional DBB contracting method is the CM-GC approach. The CM-GC process has two phases. In the design phase, the highway agency hires a construction manager to work with the designer and agency to identify risks, provide cost projections, and refine the project schedule. The construction manager and agency negotiate a price for the construction contract and, if both parties agree, the construction manager becomes the general contractor for the construction phase. As with the DB approach, agencies can save time because of the contractor's ability to undertake several activities concurrently. It also allows State DOTs to remain active in the design process while assigning risks to the parties most able to mitigate them. Sixteen DOTs and all three Federal Lands Highway Divisions are implementing the CM-GC project delivery method. Twenty projects were constructed in the past 3 years using CM-GC, and 25 more were planned for 2012 and 2013 (*Exhibit 12-4*).

Exhibit 12-4 Construction-Manager–General Contractor Process



Alternative Contracting Methods

The Michigan DOT used CM-GC to develop and deliver a complex slope-stability project quickly, safely, and cost-effectively. Both DB and CM-GC have helped the Utah DOT streamline production, reduce risk, and cut costs on many projects over the past decade. When the Utah DOT needed to complete a $1.5-billion project to rebuild a highway in time for the 2002 Salt Lake Winter Olympics, DB accelerated project completion by an estimated 4 years. On an I-80 widening job that included 14 bridges, CM-GC resulted in user cost savings of $25 million on a $140-million project. Since 2010, the Maine DOT has advanced nine DB projects and the DB method has become an established accelerated project delivery practice for the agency.

Shortening Project Delivery Toolkit

Highway projects that require environmental impact statements under the National Environmental Policy Act (NEPA) typically take 12 to 13 years to complete. In order to deliver needed projects faster, FHWA created the Shortening Project Delivery Toolkit to encourage greater use of regulatory flexibilities available under current laws. The following highlights how State DOTs are using the initiatives to streamline projects.

Expanded use of programmatic agreements. Programmatic agreements establish streamlined processes for handling routine environmental requirements on common project types. A programmatic agreement spells out the terms of a formal agreement between a State DOT and other State or Federal agencies and sets up a process for consultation, review, and compliance with applicable Federal laws. Such agreements save time in the project delivery process by specifying clear roles and responsibilities, standardizing coordination and compliance procedures, and improving relationships among DOT and regulatory agency staff.

Thirty-seven States have at least two active programmatic agreements. Since October 2010, 56 programmatic agreements have been initiated.

Programmatic Agreements

The Nebraska Department of Roads developed a programmatic agreement for a biological evaluation process. When the programmatic conditions are met at the project level, the agency no longer needs to coordinate with or obtain concurrence from FHWA, the U.S. Fish and Wildlife Service, or the Nebraska Game and Parks Commission. This agreement results in a minimum savings of 5 weeks in the project schedule for an estimated 80 percent of the projects in the State's transportation program. In another case, the Oklahoma DOT's American Burying Beetle Programmatic Biological Opinion has expedited projects by as much as a year, and it minimizes schedule uncertainty on projects where American Burying Beetles, a critical endangered species, might be present.

Enhanced technical assistance. FHWA is providing additional technical assistance to help States identify NEPA-related challenges and implement solutions to resolve project delays where feasible. Interagency coordination at all levels of government is helping move projects forward in a streamlined manner.

FHWA is focusing on new projects that are expected to experience delays and ongoing projects for which no record of decision has been issued 60 months or more after the project's notice of intent was published. Of the 10 projects on which assistance is being provided, four—in Alaska, Nebraska, North Carolina, and Utah—had a record of decision or withdrawal of the notice of intent by July 2012.

Use of in-lieu fees and mitigation banking. In-lieu fees are those charged to perform environmental enhancement activities throughout an entire watershed rather than at a particular site. Mitigation banking refers to restoring or enhancing wetlands, streams, or other resources to offset unavoidable adverse impacts related to a highway project in another area. FHWA is encouraging highway agencies to use both approaches where allowed. Thirteen of the 23 States participating in the initiative have active agreements for mitigation banking programs, and seven of those agreements extend to local agencies. Six States have agreements in place for in-lieu fees.

Planning and environmental linkages. This initiative set up a framework for considering and incorporating planning documents and decisions from the earliest stages of project planning into the environmental review process. Linking planning and environmental considerations can lead to a seamless decision-making process that minimizes duplication of effort, promotes environmental

In-Lieu Fees and Mitigation Banking

The Alaska Department of Transportation and Public Facilities has used the in-lieu fee program to meet wetland mitigation commitments on more than 70 projects since the Every Day Counts program began. Additionally, the Mississippi DOT has streamlined the compensatory mitigation permitting process for wetland and stream impacts on all applicable transportation projects. The Mississippi DOT now owns wetland and stream credits in 18 mitigation properties, perpetually conserving some 20,000 acres of land.

stewardship, and reduces project delays. To ensure that planning information and decisions are properly coordinated for use in the NEPA review process, FHWA is recommending use of the Planning and Environmental Linkages (PEL) Questionnaire, which was adapted from a questionnaire developed for use in Colorado. By July 2012, 18 of the 32 States and Federal Lands Highway Divisions participating in the initiative had made use of the PEL Questionnaire or an equivalent process.

Planning and Environmental Linkages

The Louisiana Department of Transportation and Development created a National Best Practice Planning and Environmental Linkages Checklist and is using it on all new projects to save time and money. The Montana DOT has standardized its corridor planning process through its Corridor Planning Study Checklist.

Every Day Counts Round Two

In July 2012, FHWA announced a new round of innovative technologies and processes under its Every Day Counts initiative that can shorten the time needed to open highway projects to the public and enhance safety and environmental outcomes. Over the next 2 years, expert teams will work with State transportation agencies and the design and construction industries to deploy 13 innovations.

Programmatic agreements. Also part of the first round of Every Day Counts, programmatic agreements establish streamlined approaches for handling routine environmental requirements. In this round, some of the newly developed agreements will be applied in additional States or expanded to include regions.

Locally administered Federal-aid projects. FHWA has developed a three-pronged strategy to help local agencies navigate the complexities of the Federal-Aid Highway Program. The strategies include certification and qualification-type programs, indefinite delivery–indefinite quantity consultant contracts, and stakeholder committees.

Three-dimensional modeling technology. With 3D modeling software, design and construction teams can connect virtually to collaborate on project designs throughout the design and construction phases. This technology allows for faster, more accurate, and more efficient planning and construction, in many cases increasing productivity by up to 50 percent.

Intelligent compaction. When pavement cracks prematurely, a potential cause is that it was not compacted properly during construction. Intelligent compaction—using global positioning system (GPS)-based mapping and real-time monitoring to enable adjustment of the compaction process—improves the quality, uniformity, and lifespan of pavements.

Accelerated bridge construction. FHWA is advancing three technologies to replace bridges faster, more safely, and sometimes at less cost. They are PBES, in which components are built off-site and moved into place quickly; slide-in bridge construction, in which a bridge is built next to an existing structure and slid into place; and GRS-IBS, which uses geosynthetic reinforcement and granular soils as a composite material to build abutments and approach embankments.

Design-build and construction manager–general contractor project delivery methods. FHWA is continuing its deployment of DB and CM-GC methods, accelerated project delivery methods that can shorten construction project schedules by years. Accelerated project delivery also provides opportunities for significant cost savings and safety improvements.

Alternative technical concepts. Through this flexible contracting process, contractors can recommend innovative, cost-effective solutions that are equal to or better than a State's design and construction criteria. The approach promotes competition and gives highway agencies the opportunity to choose design and construction solutions that offer the best value.

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High-friction surface treatment. This pavement technology reduces crashes, injuries, and fatalities. It involves applying high-quality aggregate with friction values far exceeding conventional pavement friction to existing or potential high-crash areas to help drivers maintain better control in dry and wet conditions.

Intersection and interchange geometrics. Innovative designs can reduce or move crossover or conflict points in intersections and interchanges, increasing safety for motorists, pedestrians, and bicyclists. Roundabouts, diverging diamond interchanges, and intersections with displaced left-turns or variations on U-turns are among the effective alternatives to traditional designs.

Geospatial data collaboration. This initiative uses cloud-based geographic information system services, which are used to build maps, to improve data sharing within agencies and among project delivery stakeholders. Collaborative analyses and rapid updating of shared maps will lead to faster consensus building, improved decisions, and better scheduling on highway projects.

Quality environmental documentation. FHWA is promoting recommendations to improve the quality and reduce the size of NEPA documents developed for construction projects. The initiative will help make NEPA documents more effective in disclosing to the public and participating agencies the information that is used to make project decisions. That, in turn, will help project proponents accelerate project delivery and achieve better environmental outcomes.

First responder training. Crashes, disabled vehicles, and road debris create unsafe driving conditions and cause about 25 percent of all traffic delays. This initiative offers the first national, multidisciplinary traffic incident management process and training program. It promotes understanding among first responders of the requirements for safe and quick clearance of traffic incidents, prompt and open communications, and motorist and responder safeguards.

Improving Safety Through Intersection Geometrics

Intersections and interchanges are planned points of conflict where motorists, pedestrians, and bicyclists cross paths or change direction. This creates conditions that could result in a crash. More than 20 percent of roadway fatalities in 2009 were intersection-related, a percentage that has not changed significantly for 25 years.

FHWA encourages highway agencies to consider alternative geometric intersection and interchange designs that reduce or alter conflict points and allow for safer travel. Past and ongoing FHWA studies of alternative intersection and interchange designs document the magnitude of both safety and operational improvements. Among the effective alternatives to traditional designs are roundabouts, diverging diamond interchanges (DDIs), and intersections with displaced left turns or variations on U-turns.

A roundabout is a circular intersection in which traffic travels counterclockwise around a central island and entering traffic must yield to circulating traffic. Roundabouts change the nature of intersection conflicts by eliminating perpendicular crossings and opposing direction turns in favor of low-speed merging and diverging maneuvers.

DDIs simplify the operation of intersections at a diamond-style interchange by removing from the signalized intersection the turns on to and off of the ramps. This is accomplished by moving traffic to the left side of the road between the ramp terminals. DDI design reduces the number of perpendicular conflict points in an equivalent conventional diamond layout.

With displaced left turns, motorists cross opposing lanes at an intersection several hundred feet from the main intersection. Motorists then travel on a road parallel to the main road until they turn left with the through-traffic at the main intersection. Similarly, U-turn designs require motorists to make a U-turn maneuver at a one-way median away from the main intersection instead of a direct left turn at the main intersection.

Exhibit 12-5 Diverging Diamond Interchange

Photo courtesy of FHWA.

A New Way of Doing Business

Through the Center for Accelerating Innovation, FHWA provides both national leadership and State-based assistance in the effort to shorten project delivery, improve roadway safety, and protect the environment. Having access to the flexibilities and technologies available through Every Day Counts can help highway agencies add value to projects or expedite project delivery where appropriate. This collaborative approach facilitates accelerated deployment of proven solutions that can make a difference. It will result in development of a national network of transportation professionals skilled in the rapid deployment of innovation.

Ultimately, the focus of FHWA innovation initiatives such as Every Day Counts is greater than specific technologies or strategies. The long-term goal of the Center for Accelerating Innovation is to institutionalize innovations by incorporating them into the standards, specifications, and manuals that highway professionals use every day. Its aim is to foster a culture of innovation throughout the highway community. The result will be a new way of doing business that embraces innovation and uses it to meet the Nation's transportation needs in the 21st Century.

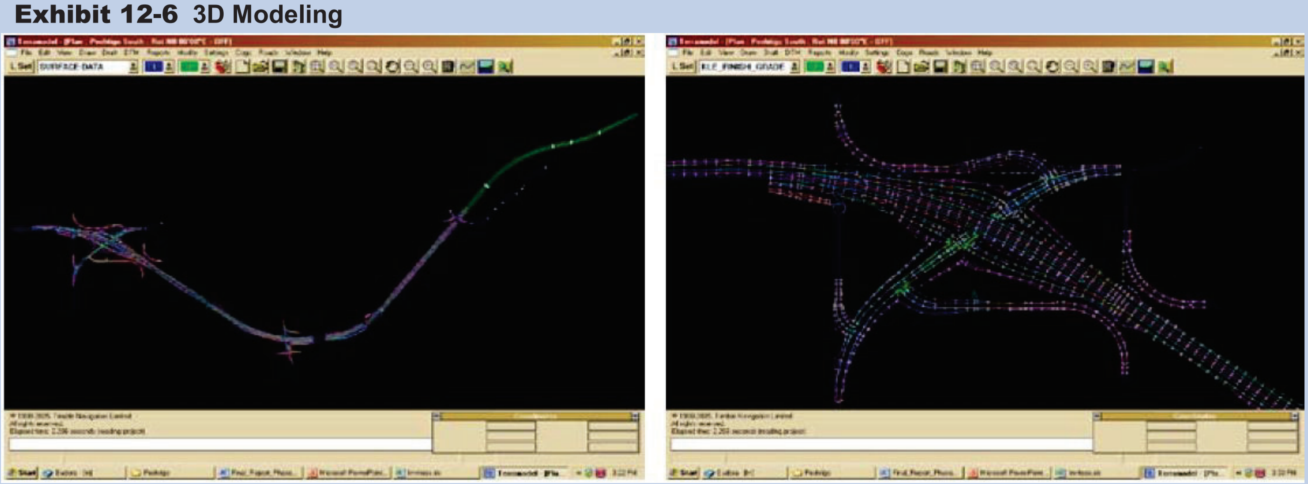
Enhancing Project Delivery With 3D Modeling

Using 3D modeling in transportation construction allows for faster, more accurate, and more efficient planning and construction. With 3D modeling software, design and construction teams can connect virtually to develop, test, and alter project designs throughout the design and construction phases. Intricate design features can be viewed in 3D from multiple perspectives, and simulations can be run to detect design flaws before construction begins.

Data exported from 3D models can be transferred to GPS machine control that guides construction equipment such as bulldozers and excavators. Combining 3D modeling and GPS machine control helps highway agencies complete highway projects faster with improved quality and safety. GPS-enabled construction equipment can run all day and night with guidance from 3D model data and achieve accurate grades on the first pass, reducing waste and improving resource use.

The combined technologies of 3D modeling and GPS machine control can increase productivity by up to 50 percent for some operations and cut survey costs by up to 75 percent. Reduced idle time of equipment and reduced rework lowers fuel consumption and associated greenhouse gas emissions by up to 40 percent. Now used in numerous States, 3D technology is proving to be a cost-effective way to accelerate highway construction.

Exhibit 12-6 3D Modeling



Source: FHWA.

Using Intelligent Compaction to Improve Pavement Quality

Compaction is one of the most important processes in roadway construction. When pavement crumbles before it reaches its expected lifespan, a potential cause is that it was not compacted properly or the thickness is not uniform. Intelligent compaction (IC) technology improves the quality, uniformity, and long-lasting performance of pavements.

Using vibration and a system to collect, process, and analyze measurements in real time, IC rollers can compact more pavement with fewer passes than traditional rollers. IC efficiencies result in time, cost, and fuel savings. With more efficient paving processes, production can increase and highway agencies can pave larger roadway sections daily.

Using GPS-based mapping and an onboard computer reporting system, IC roller operators can monitor and provide immediate corrections to the compaction process. A continuous record of color-coded plots records the number of roller passes, compaction measurement values, and precise location of the roller. The system analyzes the data and compares the results of previous passes to determine whether adjustments are needed.

Expanding IC use nationwide is a cost-effective way to accelerate highway pavement construction. Cost-benefit analyses show that investment in IC will break even in 1 to 2 years. Use of IC technology will produce better-quality roadways that help keep motorists safe and allow highway agencies to operate more efficiently.

Exhibit 12-7 Intelligent Compaction

Photo courtesy of FHWA.

CHAPTER 13

National Fuel Cell Bus Program

National Fuel Cell Bus Program

This chapter summarizes accomplishments of fuel cell transit bus research and demonstration projects supported by the Federal Transit Administration (FTA) through 2011. It describes fuel cell electric bus (FCEB) research projects in the United States and describes their impact on commercialization of fuel cell power systems and electric propulsion for transit buses in general.

FTA conducts most of its FCEB research under the National Fuel Cell Bus Program (NFCBP), a cooperative research, development, and demonstration program to advance commercialization of FCEBs. The NFCBP is a part of a larger FTA research program to improve transit efficiency and contribute to environmentally sustainable transportation. The FTA conducts the NFCBP in partnership with industry. Projects target research to improve performance and lower costs of next-generation fuel cell systems for transportation.

Congress established the NFCBP in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). FTA's research to develop FCEBs has been under way since 2006. The NFCBP requires an equal cost share by project teams for each Federal dollar invested, bringing the size of the program to more than $150 million through FY 2011.

Transit buses are well suited to demonstrating fuel-cell applications in transportation because:

- They are centrally located and fueled
- They are government subsidized
- They are professionally operated and maintained
- They operate on fixed routes and fixed schedules
- They tolerate the weight and volume requirements of advanced systems
- They have rigorous start-up and pull-out requirements
- They provide public exposure to the benefits of advanced technologies, which leads to greater public acceptance.

NFCBP objectives, which apply to all FTA-funded FCEB research, are:

- Significantly advance development of FCEBs and related infrastructure through innovation of FCEB design, component development, improved systems integration, and real-world implementation and demonstration
- Document the state of FCEB technologies development, and examine requirements and next steps for market introduction
- Enhance awareness and education related to FCEBs and related infrastructure.

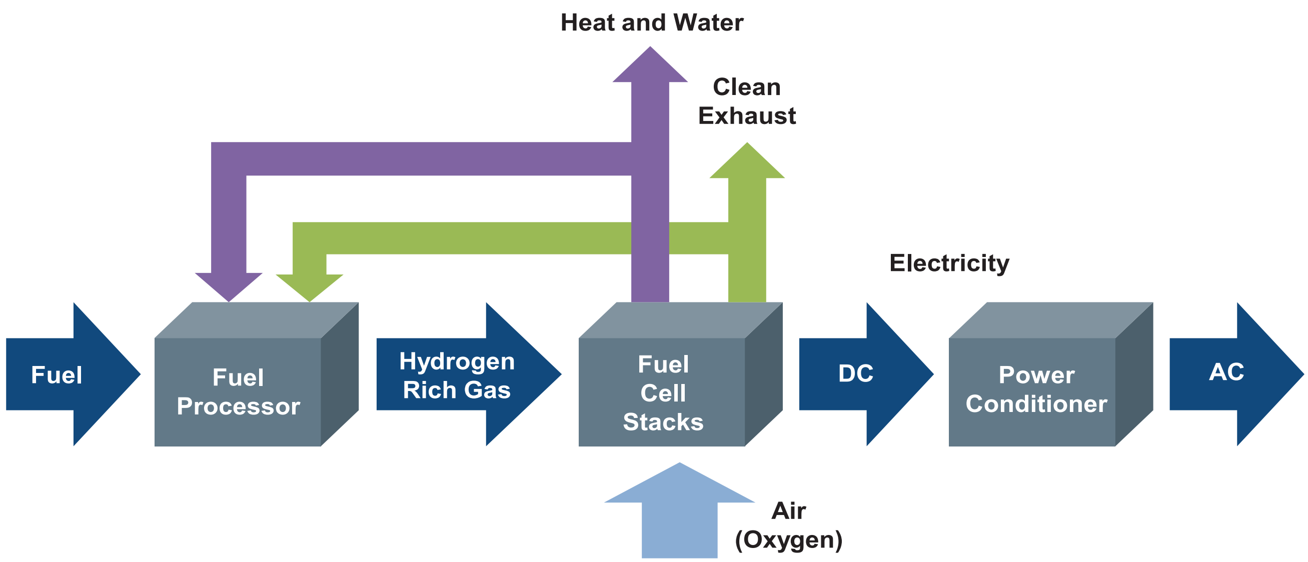
Value and Challenges of Fuel Cell Electric Propulsion for Transit Buses

U.S. interest in hydrogen FCEBs has grown over the past 20 years, driven primarily by the desire to reduce both petroleum-based fuel consumption and emissions, particularly greenhouse gas emissions. In October 2010, the U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) introduced a program to reduce greenhouse gas emissions and improve fuel efficiency of medium- and heavy-duty trucks and buses. These federal programs will significantly impact transit bus propulsion products in the future.

Exhibit 13-1 illustrates fuel cell operation. Fuel cell electric technology for transit buses can produce benefits such as:

- Zero tailpipe emissions
- Improved fuel economy
- Reduced dependence on foreign oil
- Quiet, smooth ride
- Creation of green technology jobs
- Technologies for better-performing, more-efficient hybrid and electric buses
- Demonstration of the value of fuel cell technology to a larger, heavy-duty vehicle market.

Exhibit 13-1 **Diagram of Fuel Cell Operation**



Source: Department of Energy, Fuel Cell Report to Congress (ESECS EE-1973), February 2003.

The major barriers to reaching full commercialization of FCEBs are:

- Durability – The useful life of fuel cell power systems is increasing, but more work is needed to meet transit requirements.
- Initial purchase costs – The cost of buses and infrastructure is decreasing, but to become competitive the market will need to realize economies of scale through greatly expanded production.
- Delivery of "green" hydrogen – The availability and cost of hydrogen for FCEB operations remain significant barriers. Hydrogen is produced by electrolysis or through natural gas reforming, or it is trucked as a liquid into operating locations. These production and delivery methods all pose cost and greenhouse gas emission issues that must be resolved before FCEBs are fully commercialized.

Accomplishments from FTA research on Fuel Cell Bus Technology:

- Design – Seven fully integrated FCEB designs are now available, in either a fuel cell dominant or battery dominant configurations.
- Manufacture – The NFCBP funded Proterra's first bus, a battery dominant FCEB that operated in Columbia, South Carolina, and will soon operate in Austin, Texas.
- Demonstration – The newest-generation Van Hool/UTC Power FCEB design was delivered, with 12 buses going to the San Francisco Bay Area and 4 buses going to Hartford, Connecticut. These 16 FCEBs are the largest demonstration of one FCEB design in the United States.
- Reliability – As of the end of 2011, one of the Bay Area buses has a fuel cell power system with 11,000 hours of operation without significant maintenance (i.e., no change out of the fuel cell system or individual cells) and other buses in the fleet have fuel cell power systems with 6,000 and 8,000 hours of operation without significant maintenance.
- Buy America – FTA has made progress in integrating FCEBs that are "Buy America" compliant. Ballard, a major supplier, is producing systems in Lowell, Massachusetts; and UTC Power, another major supplier, is working toward packaging its system for easier integration into buses from U.S. manufacturers.
- Fueling Infrastructure – Ongoing demonstrations are facilitating a better understanding of needed infrastructure and safe operations for existing transit operations.
- Hybrid Propulsion – FTA-funded research is leading to better components and the integration of electric systems for electric propulsion.
- Public Awareness – FTA research projects support awareness and education for transit agencies and the public. FTA has funded outreach through National and International Fuel Cell Bus Workshops, and develops research reports for industry.

History and Status of FCEB Research

FTA FCEB propulsion and infrastructure demonstrations began in the early 1990s with buses developed at Georgetown University. These 30- and 40-foot buses were fueled by methanol that was reformed into hydrogen onboard and used in the buses' electric fuel cell propulsion systems. Between 1998 and 2000, the FTA supported a second major demonstration of three, 40-foot hydrogen fuel cell buses, with Ballard fuel cells, operated at Chicago Transit Authority (CTA). During this same time period, three fuel cell buses of the same generation also operated in Vancouver, Canada.

FTA's early demonstrations proved the feasibility of fuel cell propulsion for transit buses and identified research needed to:

- Reduce the size of fuel cell stacks and balance-of-plant onboard buses
- Increase power density of the fuel cell power system
- Reduce the weight of fuel cell and electric propulsion systems
- Develop a hydrogen fueling infrastructure suitable for transit bus operations.

The first "next-generation" FCEB, a 40-foot bus with a Ballard fuel cell power system, operated at SunLine Transit Agency (SunLine) during 2000 and 2001. A second "next-generation" FCEB, a 30-foot bus with a UTC Power fuel cell power system, operated first at SunLine and then at Alameda-Contra Costa Transit District (AC Transit) during 2002 and 2003.

In August 2005, Congress established the National Fuel Cell Bus Technology Development Program to facilitate development of commercially viable FCEB propulsion technologies. The FTA released the initial competitive solicitation for the NFCBP on April 10, 2006. A multi-department technical team recommended 14 projects for funding under the program. Projects included partners from

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industry, government, and transit and provided a balanced portfolio for the NFCBP to advance FCEB commercialization. The NFCBP continued beyond its initial four years, funded through extensions of SAFETEA-LU for FY 2010 and FY 2011. Each annual extension added approximately $13.5 million, for a total of nearly $76 million in federal funding through FY 2011. The 50 percent cost share requirement was also continued for all projects, bringing funding for the program to more than $150 million.

NFCBP projects are managed through one of three non-profit consortia:

- CALSTART – a nonprofit consortium headquartered in Pasadena, California. CALSTART represents more than 140 firms. It provides services and consulting to develop clean, advanced transportation technologies for all types of vehicles, including trucks, buses, and military vehicles.
- Center for Transportation and the Environment (CTE) – a nonprofit consortium headquartered in Atlanta, Georgia. CTE provides research, training, and information exchange for improving transportation infrastructure while preserving the integrity of the environment.
- Northeast Advanced Vehicle Consortium (NAVC) – a nonprofit, public-private partnership headquartered in Boston, Massachusetts. NAVC conducts research and technology analysis and fosters information sharing and collaboration on advanced vehicle technology projects.

Current FTA FCEB research focuses on developing transit buses that demonstrate full transit operation and service. Current bus configurations have either large fuel cell power systems in hybrid electric propulsion systems or smaller fuel cell power systems in plug-in/battery dominant hybrid electric propulsion systems. Ongoing research also includes electrifying accessories (e.g., air conditioning) and, in some cases, adding small fuel cell auxiliary power units (APUs) to power the electric accessories.

The U.S. Department of Energy (DOE) also funds FCEB research. Most of DOE's fuel cell and hydrogen research is done through the Fuel Cell Technologies Program within the Office of Energy Efficiency and Renewable Energy (EERE). DOE's research in fuel cells and hydrogen complements FTA's transit bus research and demonstration, usually through DOE's investment in developing technologies used in the demonstrations. For example, the DOE supported hydrogen fueling stations at several demonstration locations in California. In addition, DOE's Clean Cities program provides grants for clean energy projects that include a hydrogen fueling station planned for CTTRANSIT in Hartford, Connecticut.

In March 2012, the FTA released a report, FTA Fuel Cell Bus Program: Research Accomplishments through 2011, (http://www.fta.dot.gov/documents/FTA_Report_No._0014.pdf) that summarizes 42 research projects, including NFCBP projects, other FTA research, and supporting research funded by the DOE. To date, 17 of these projects have been completed and 25 are ongoing FTA and DOE projects.

Research Accomplishments

Research under the NFCBP shows progress toward commercialization and readiness for implementation of FCEBs in transit operations. The NFCBP has seven performance objectives for the research projects it funds. *Exhibit 13-2* lists these objectives and summarizes progress toward meeting them. Although progress is significant, more investment is needed to meet the objectives.

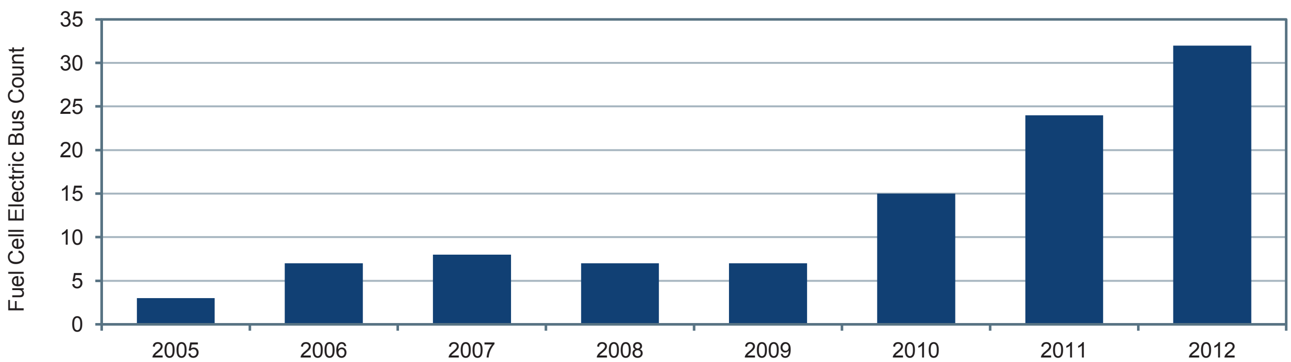
Exhibit 13-3 shows the number of FCEBs operating in the United States. Between 2005 and 2009, potential regulation by the California Air Resources Board was the impetus for FCEB research, and the first seven FCEBs operated in California at SunLine, Santa Clara VTA, and AC Transit. Beginning in 2007, one FCEB began operating at CTTRANSIT in Hartford, Connecticut.

Exhibit 13-2 **Progress Toward Achieving Technical Performance Objectives**

NFCBP Performance Objective	Progress Through FY 2011
1. Less than five times the cost of a conventional (commercial diesel) transit bus	Cost reductions from more than $3.0 million per bus in 2006 to $2.3 million for last bus ordered. Battery dominant bus with smaller fuel cell power system significantly less than $2.3 million.
2. Four to six years or 20,000 to 30,000 hours of durability for the fuel cell power system	10,000+ hours achieved on fuel cell power system, with durability warranties at 10,000 to 12,000 hours.
3. Double the fuel economy compared to commercial (diesel transit) bus	Exceed two times conventional (diesel transit) bus fuel economy, but depends on route.
4. Bus performance equal to or greater than equivalent commercial (diesel transit) bus	Operated up to 19 hours/day, with good availability, and miles between road calls at 4,000 miles. Better acceleration. Quiet operation. Weight is still high.
5. Exceed current emissions standards	Zero emissions.
6. Foster economic competitiveness in FCEB technologies	Multiple manufacturers and platforms demonstrating buses.
7. Increase public acceptance for FCEB technologies	Continued progress.

Source: FTA, FTA Fuel Cell Bus Program: Research Accomplishments through 2011, FTA Report No.14, March 2012.

Exhibit 13-3 **Fuel Cell Electric Buses Operating in the United States, 2006–2012**



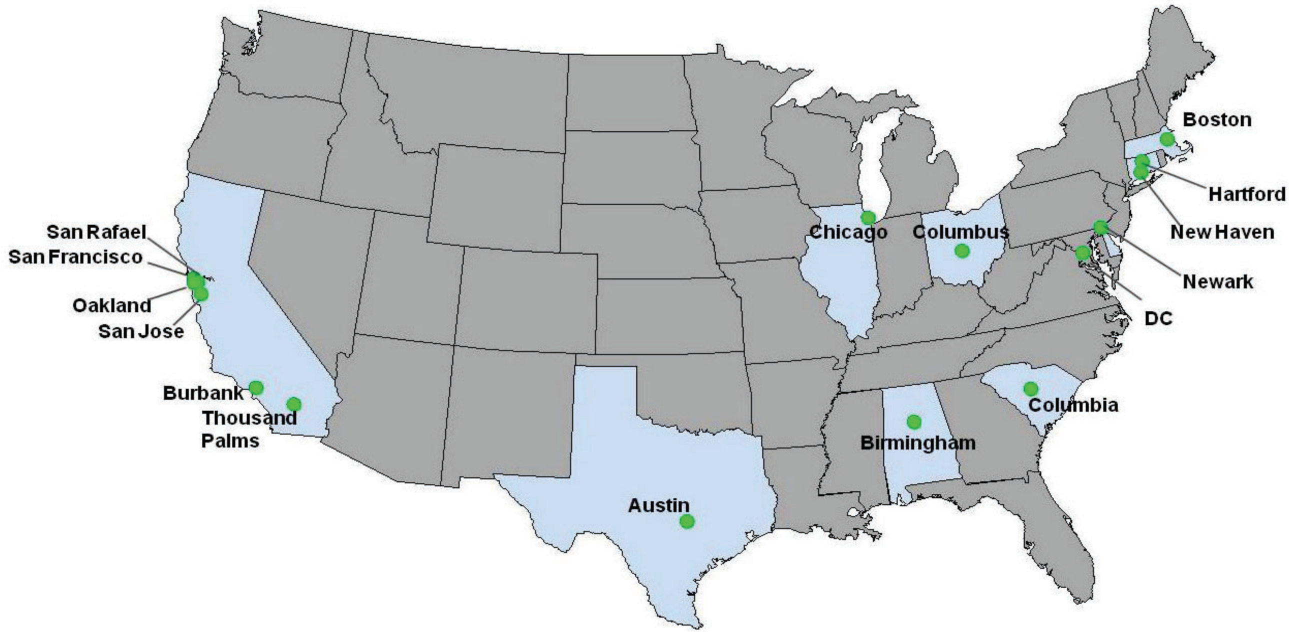
Source: FTA, FTA Fuel Cell Bus Program: Research Accomplishments through 2011, FTA Report No.14, March 2012.

Funding though the NFCBP was available starting in 2006. However, its influence becomes apparent only in 2010, due to the lag time between designing and building FCEBs and getting them into operation. The projected number (32) of FCEBs that will be in operation by the end of 2012 is conservative.

Exhibit 13-4 is a map of current or planned FCEB operating locations. FCEB demonstrations have expanded and are now located across the United States, not just in California.

The 42 projects discussed in the FTA report represent multiple design configurations for FCEBs. *Exhibit 13-5* shows the current fully integrated FCEB configurations and their manufacturers. Three are fuel cell dominant configurations, and four are battery dominant fuel cell configurations. The design configurations represent seven bus manufacturers and three fuel cell power system manufacturers. Another FCEB is planned with a fourth fuel cell power system manufacturer, Nuvera. In addition to those listed in the table, one existing hybrid electric bus design, Orion VII, BAE Systems, was modified using all-electric accessories powered by a small fuel cell power system by Hydrogenics. This modified design also provides some power for all-electric operation of the power plant dominant hybrid.

Exhibit 13-4 Fuel Cell Electric Bus Demonstration Sites



Source: FTA, FTA Fuel Cell Bus Program: Research Accomplishments through 2011, FTA Report No.14, March 2012.

Exhibit 13-5 Fuel Cell Bus Configurations

Bus Manufacturer	Fuel Cell System	Hybrid System	Hybrid Configuration	Energy Storage	Status
Van Hool 40-ft	UTC Power	Siemens ELFA	Fuel cell dominant	Lithium-based batteries	Operational
ElDorado 40-ft	Ballard	BAE Systems	Fuel cell dominant	Lithium-based batteries	Operational
New Flyer 40-ft	Ballard	Siemens ELFA	Fuel cell dominant	Lithium-based batteries	Operational
Proterra 35-ft	Hydrogenics or Ballard	Proterra integration	Battery dominant	Lithium-based batteries	Operational
DesignLine 35-ft	Ballard	DesignLine integration	Battery dominant	Lithium-based batteries	Under development
Ebus 22-ft	Ballard	Ebus integration	Battery dominant	Nickel cadmium batteries	Operational
EVAmerica 30-ft	Ballard	EVAmerica integration	Battery dominant	Lithium-based batteries	Under development

Source: FTA, FTA Fuel Cell Bus Program: Research Accomplishments through 2011, FTA Report No.14, March 2012.

In 2007, Proterra, a new "green" bus manufacturer, started design of and delivered its first bus, a battery dominant hybrid fuel cell bus, for demonstration in Columbia, South Carolina (completed in 2010), and Austin, Texas (planned to start in 2012). The NFCBP helped Proterra acquire the start-up capital to begin manufacturing this bus. Since then, Proterra has built and delivered two more FCEBs that are essentially the same as the first one. Proterra based its propulsion system on an all-electric design with the capability to add a fuel cell power system as a range extender. Its buses are also designed for opportunity charging while on route. Foothill Transit (West Covina, California) purchased three electric buses with one of Proterra's fast charging stations. Proterra is assembling another 10 or more buses for transit operations in other locations.

Several transit agencies in California began testing FCEBs because of potential state regulation and purchase requirements for zero-emission buses. Beginning in 2005, this testing included an FCEB design from Van Hool, UTC Power, and ISE (now Bluways), with energy storage in ZEBRA batteries. SunLine operated one of these buses and AC Transit operated three more. Two additional buses of this design operated in Belgium and at CTTRANSIT in Hartford, Connecticut.

The NFCBP funded UTC Power and AC Transit to maximize operation of AC Transit's three FCEBs (i.e., accelerated testing) to study reliability, durability, and failure modes of the fuel cell power system. This accelerated testing began in late 2007. The lessons learned and improvements to the design of the UTC Power fuel cell power system increased durability so that one of the systems reached 11,000 operating hours without significant maintenance, and two others have accumulated 6,000 and 8,000 operating hours without significant maintenance. Previous fuel cell power systems reached only about 4,000 operating hours before a low power output level indicated the end of useful life for the systems.

Following these initial testing activities, AC Transit, Van Hool, and UTC Power designed and developed an improved "next-design" FCEB for the Zero Emission Bay Area (ZEBA) advanced demonstration in California. AC Transit is leading a group of San Francisco Bay Area (Bay Area) transit agencies in this demonstration. The demonstration includes 12 new FCEBs and two new hydrogen fueling stations at two AC Transit operating depots. UTC Power and CTTRANSIT are demonstrating four more "next-design" FCEBs in Hartford, Connecticut. Demonstration of the "next-design" version of Van Hool/UTC Power FCEBs now includes 16 buses in two locations, making it the largest FCEB demonstration in the United States.

Buy America requirements (Title 49 CFR Part 661), set standards for federally assisted procurements, specifically: "…no funds may be obligated by FTA for a grantee project unless all iron, steel, and manufactured products used in the project are produced in the United States." In 2008, FTA granted a public interest waiver to the FTA Buy America requirements for NFCBP projects, so that project teams could access all available technologies and components, regardless of origin, in order to hasten the development of fuel cell technology for transit. This allowed teams to access a full slate of technologies, many of which were not readily available domestically, for validating fuel cell bus technology, with the overall goal to stimulate and further expand the U.S. fuel cell bus industry. Over the past few years, FTA and the consortia have made progress toward meeting "Buy America" requirements:

- The FTA-funded ElDorado/BAE Systems/Ballard as new manufacturer partners to develop and demonstrate a new FCEB at SunLine and CTA. The new bus meets Buy America requirements, and is assembled in Riverside, CA.
- Increasing orders for FCEBs in the United States led Canadian-based fuel cell manufacturer, Ballard Power Systems, to establish manufacturing capabilities for fuel cell power systems in Lowell, Massachusetts. Fuel cell power systems are the largest cost component of FCEBs. Their availability in the United States helps bus manufacturers meet Buy America requirements.
- The UTC Power fuel cell power system is currently only available in Van Hool buses from Belgium. The NFCBP funded a project with Connecticut-based fuel cell manufacturer, UTC Power, to engineer, package, and test a further optimized fuel cell power system that can be installed easily into U.S. bus manufacturer models.

Hybrid electric propulsion for transit buses increases energy efficiency for the buses, but it also increases complexity. Hybrid electric propulsion has the potential to reduce maintenance costs through fewer moving parts, battery energy storage, and regenerative braking, which reduces both brake wear and brake maintenance. The challenges for hybrid electric propulsion for buses are reliability and durability of the major components and optimized integration, especially software integration.

FTA funding for FCEB research enabled several bus manufacturers and integrators to gain experience in building and optimizing electric propulsion systems. It also enabled BAE Systems, a commercial electric propulsion manufacturer/supplier, to enter the FCEB market. With NFCBP funding, BAE Systems electrified accessories in its Compound Bus 2010 project, which led to an electric accessory package that will be integrated into its commercial hybrid products in the future. In addition, the NFCBP funded development of critical power electronics components for hybrid electric propulsion systems, such as DC-DC convertors. All of this research expands the availability of products to the transit industry.

Hydrogen fuel for FCEB demonstration projects is typically supplied through electrolysis or natural gas reforming, or it is trucked into a fueling site as liquid or high-pressure gas. The FTA has invested in all of these methods to support not only the development of hydrogen fueling infrastructure, but also safe operations in and around transit maintenance, storage, and wash facilities. In addition, the FTA funded the Volpe Center to review safety plans for transit FCEB operations and infrastructure as well as to provide technical assistance to each transit agency operator of FCEBs.

An objective of all FTA research is to share results and lessons learned. Information sharing is a specific objective of the NFCBP, including lessons learned from FCEB and infrastructure research to facilitate technical progress and future research. FCEB development and demonstration reports document implementation to facilitate understanding of the requirements for market introduction.

All NFCBP demonstration projects include an awareness and education component. Transit agencies that operate FCEBs are able to educate their passengers and the communities through outreach and public events. Through FY 2011, the NFCBP has funded and/or produced 10 brochures and 29 reports about FCEB research.

The NFCBP also established both a national and an international working group for information sharing and cooperation. The FTA initiated the International Fuel Cell Bus Working Group and workshops in 2002 to facilitate information sharing on worldwide FCEB demonstrations and to harmonize data collection to better understand the status of the technologies. Since the first workshop in 2002, the FTA has facilitated six more workshops.

The FTA formed the National Fuel Cell Bus Working Group for information sharing about FCEB demonstrations in the United States. To facilitate participation from transit agencies around the country, the working group usually meets in conjunction with American Public Transportation Association (APTA) conferences. The working group was initiated at the 2002 APTA EXPO in Las Vegas, Nevada, and since that time has held three additional meetings to discuss national demonstrations and progress toward commercialization.

The FTA intends to continue efforts to collaborate and coordinate with industry on FCEBs through outreach efforts with CTE to conduct a series of webinars on FCEB for the transit industry, and a new website on worldwide activities and developments on fuel cell buses, that will help facilitate national and international data sharing.

PART IV

Recommendations for HPMS Changes

Recommendations for HPMS Changes

Section 52003 of the Moving Ahead for Progress in the 21st Century Act (MAP-21) added a requirement for this report to include recommendations on changes to the Highway Performance Monitoring System (HPMS) that address: "(i) improvements to the quality and standardization of data collection on all functional classifications of Federal-aid highways for accurate system length, lane length, and vehicle-mile of travel; and (ii) changes to the reporting requirements authorized under section 315 to reflect recommendations under this paragraph for collection, storage, analysis, reporting, and display of data for Federal-aid highways and, to the maximum extent practical, all public roads." Part IV of this report is intended to begin to address this requirement; future editions of the C&P report will contain updates as progress is made in implementing improvements to the HPMS and as other potential changes are identified.

The HPMS is a major data source for the analyses presented in Chapters 2, 3, 7, 8, 9, and 10 of this report; the HPMS is also discussed in Appendices A and D.

Background

The Highway Performance Monitoring System (HPMS) is an annual collection of information on the extent, condition, performance, use, and operating characteristics of the Nation's highways. It was first developed in 1978 to replace numerous uncoordinated annual State data reports and special studies. HPMS includes key data on all public roads, more detailed data for a sample of the arterial and collector functional systems, complete (full extent) coverage of the Interstate and other principle arterials, and other statewide summary data.

HPMS provides essential information for apportioning Federal-aid funds to the States and for assessing highway system performance under the Federal Highway Administration's (FHWA's) strategic planning process. Pavement condition data, congestion-related data, and traffic data are used extensively to measure progress in meeting the objectives embodied in the FHWA's Performance Plan and other strategic goals. It also supports the biennial C&P Reports to Congress.

In addition, the HPMS serves needs of the States, metropolitan planning organizations, and local governments in assessing highway condition, performance, air quality trends, and future investment requirements. Data from HPMS are the source of a large portion of the information included in FHWA's annual Highway Statistics report and other publications.

HPMS is a collaborative effort between FHWA and the States. The States are responsible for collecting and reporting the data, and FHWA reviews the data for quality and consistency, provides guidance on data collection, and offers technical support on improving data quality. As much as possible, States employ common practices, such as American Association of State Highway and Transportation Officials and American Society for Testing and Materials standards, to enable consistency among the States. There is a National Cooperative Highway Research Program study currently underway (20-24[82]), "Increasing Consistency in the Highway Performance Monitoring System for Pavement Reporting," that will identify and prioritize measures that might be taken to further reduce any inconsistencies on pavement performance information.

Periodically, there is a reassessment of the HPMS to ensure that it is still fulfilling its role as the repository for national highway performance data and to recommend changes to improve it. The most recent reassessment began in 2006 and led to the elimination of data items no longer needed and the inclusion of additional

data items required by its users. It also introduced a new geospatial data model to allow more efficient data processing and geospatial analysis. After a series of intensive outreach workshops and webinars, the HPMS Reassessment 2010+ Final Report was issued in September 2008.

The new HPMS requirements have been in effect starting with the submittal of data collected in 2009. This led to the development of a new geospatial database management system that incorporates State linear referencing systems to locate highway sections. In other words, the HPMS data are attached to the State's highway map, which allows the HPMS data to be mapped and spatially analyzed.

The forthcoming 2012 edition of the Traffic Monitoring Guide (TMG) will be the basis for travel data collected by the States and reported to FHWA. This new edition will provide improved guidance on the methods for properly collecting, analyzing, and reporting travel data. One of the new data areas in HPMS that will benefit from the forthcoming TMG will be traffic counts on ramps. The new HPMS requires States to submit basic information for all ramps including: ramp length, functional class, number of lanes, and annual average daily traffic.

Changes to HPMS

MAP-21 indirectly made two changes to HPMS by expanding the National Highway System (NHS) to include all principal arterials. This leads to increased data collection for truck travel data in HPMS, which must cover the NHS while being sampled elsewhere, and International Roughness Index (IRI) data, which must be collected annually on the NHS in contrast to biennially elsewhere.

HPMS will serve as the foundation for linking FHWA data systems, which will enable more comprehensive analyses thanks to the combining of the financial and bridge data with the highway information in HPMS. On August 7, 2012, FHWA notified the States that, starting with data submitted in 2014, it is asking States to provide geospatial information for their road network on all public roads. This information will allow FHWA to build a national basemap for an integrated system of highway attributes for analysis of safety, bridge, freight, and planning data. Also included is a requirement for States to provide dual networks for all divided highways. This will enable the States to provide FHWA their highway attribute data by roadway direction, which is more convenient for many States.

FHWA is considering a possible change to the reporting requirements of the IRI data that are used for performance measurement of pavement condition. This change would standardize the section length required for reporting IRI so that comparisons are consistent. Currently, States use different IRI section lengths, although the most common is one-tenth of a mile.

Q&A

What does the term "dual network" mean?

The geospatial networks, or maps, that States currently submit in HPMS are considered a single centerline network, which means that the networks use only single lines to represent all roads regardless of whether the roads are two-lane collectors or divided Interstate. To contrast, the dual network is two lines for all divided highways, one for each of the directional roadways. This allows for a more accurate spatial representation of divided highways, improves data quality for these roads, and enhances analysis capabilities.

PART V

Appendices

Introduction

Appendices A, B, and C describe the modeling techniques used to generate the investment/performance analyses and selected capital investment scenario estimates highlighted in Chapters 7 through 10. Appendix D discusses crosscutting analytical issues.

Appendix A describes selected technical aspects of the **Highway Economic Requirements System** (HERS), which is used to analyze potential future investments for highway resurfacing and reconstruction and highway and bridge capacity expansion.

Appendix B describes the **National Bridge Investment Analysis System** (NBIAS), which is used for analyzing potential future bridge rehabilitation and replacement investments.

Appendix C presents technical information on the **Transit Economic Requirements Model** (TERM), which is used to analyze potential future transit investments in urbanized areas. TERM includes modules which estimate the funding that will be required to replace and rehabilitate transit vehicles and other assets and to invest in new assets to accommodate future transit ridership growth.

Appendix D describes ongoing research activities and identifies potential areas for improvement in the data and analytical tools used to produce the highway, bridge, and transit analyses contained in this report.

APPENDIX A

Highway Investment Analysis Methodology

Highway Investment Analysis Methodology

Investments in highway resurfacing and reconstruction and in highway and bridge capacity expansion are modeled by the Highway Economic Requirements System (HERS), which has been used since the 1995 C&P Report. This appendix describes the basic HERS methodology and approach in slightly more detail than is presented in Part II including the model features that have changed significantly since the 2010 C&P Report: the valuation of travel time and the equations for emissions costs

Highway Economic Requirements System

The HERS model begins the investment analysis process by evaluating the current state of the highway system using information on pavements, geometry, traffic volumes, vehicle mix, and other characteristics from the Highway Performance Monitoring System (HPMS) sample dataset. Using section-specific traffic growth projections, HERS forecasts future conditions and performance across several funding periods. As used in this report, the future analysis covers four consecutive 5-year periods. At the end of each period, the model checks for deficiencies in eight highway section characteristics: pavement condition, surface type, volume/service flow (V/SF) ratio (a measure of congestion), lane width, right shoulder width, shoulder type, horizontal alignment (curves), and vertical alignment (grades).

After HERS determines that a section's pavement or capacity is deficient, it identifies potential improvements to correct some or all of the section's deficient characteristics. The HERS model evaluates seven kinds of improvements: resurfacing, resurfacing with shoulder improvements, resurfacing with widened lanes (i.e., minor widening), resurfacing with added lanes (i.e., major widening), reconstruction, reconstruction with widened lanes, and reconstruction with added lanes. For reconstruction projects, the model allows for upgrades of low-grade surface types when warranted by sufficient traffic volumes. For improvements that add travel lanes, HERS further distinguishes between those that can be made at "normal cost" and those on sections with limited widening feasibility that could only be made at "high cost." HERS may also evaluate alignment improvements to improve curves, grades, or both.

Q&A

Where can I find more detailed technical information concerning the HERS model?

The most recent comprehensive documentation of the HERS model is a Technical Report from December 2000 that is based on the version of HERS used in the development of the 1999 C&P Report. An updated Technical Report based on the version of HERS used for the 2012 C&P Report will be released in 2013.

More current documentation is available for a modified version of HERS that the Federal Highway Administration developed for use by States. This model, HERS-ST, builds on the primary HERS analytical engine with a number of customized features to facilitate analysis on a section-by-section basis. The 2005 Technical Report on HERS-ST describes a version largely based on the version of HERS that was used to develop the 2004 C&P Report. See http://www.fhwa.dot.gov/asset/hersst/pubs/tech/tech00.cfm for more information.

When evaluating which potential improvement, if any, should be implemented on a particular highway section, HERS employs incremental benefit-cost analysis. Such an analysis compares the benefits and costs of a candidate improvement relative to a less-aggressive alternative—for example, reconstructing and adding lanes to a section may be compared with reconstruction alone. The HERS model defines benefits as reductions in direct highway user costs, agency costs, and societal costs. Highway user benefits include reductions in travel time costs, crash costs, and vehicle operation costs (e.g., fuel, oil, and maintenance costs); agency benefits include reduced routine maintenance costs (plus the residual value of projects with longer expected service lives than the alternative); and societal benefits include reduced vehicle emissions.

Increases in any of these costs resulting from a highway improvement (such as higher emissions rates at high speeds or the increased delay associated with a work zone) would be factored into the analysis as a negative benefit ("disbenefit").

Dividing these improvement benefits by the capital costs associated with implementing the improvement results in a benefit-cost ratio (BCR) that is used to rank potential projects on different highway sections. The HERS model implements improvements with the highest BCR first. Thus, as each additional project is implemented, the marginal BCR declines, resulting in a decline in the average BCR for all implemented projects. However, until the point where the marginal BCR falls below 1.0 (i.e., costs exceed benefits), total net benefits continue to increase as additional projects are implemented. Investment beyond this point is not economically justified because it would result in a decline in total net benefits.

Because the HERS model analyzes each highway section independently rather than the entire transportation system, it cannot fully evaluate the network effects of individual highway improvements. Although efforts have been made to indirectly account for some network effects, HERS is fundamentally rooted to its primary data source, the national sample of independent highway sections contained in the HPMS. To fully recognize all network effects, it would be necessary to develop significant new data sources and analytical techniques.

Highway Operational Strategies

One of the key modifications to HERS featured in previous reports was the ability to consider the impact of highway management and operational strategies, including Intelligent Transportation Systems (ITSs), on highway system performance. This feature is continued in this report with only minor modifications. Current and future investments in operations are modeled outside of HERS, but the impacts of these deployments affect the model's internal calculations and, thus, also affect the capital improvements considered and implemented in HERS.

Among the many operational strategies available to highway agencies, HERS considers only certain types based on the availability of suitable data and empirical impact relationships. Grouped by category, these are:

- Arterial Management
  - Signal Control
  - Electronic Roadway Monitoring (considered a supporting deployment necessary to other operations strategies)
  - Variable Message Signs (VMS)
- Freeway Management
  - Ramp Metering (preset and traffic-actuated)
  - Electronic Roadway Monitoring (considered to be a supporting deployment necessary to other operations strategies)
  - VMS
  - Integrated Corridor Management, with and without comprehensive deployment of Vehicle Infrastructure Integration (VII) technologies[1]. Integrated Corridor Management coordinates the operation of the infrastructure elements within a corridor—for example, the timing of traffic signals near freeway interchanges with freeway incident management and ramp metering
  - Active Traffic Management, which includes lane controls, queue warning systems, and Variable Speed Limits (VSL), also known as "speed harmonization"

- Incident Management (freeways only)
  - Incident Detection (free cell phone call number and detection algorithms)
  - Incident Verification (surveillance cameras)
  - Incident Response (on-call service patrols)
- Traveler Information
  - 511 systems
  - Advanced in-vehicle navigation systems with real-time traveler information (enabled by VII deployment)
  - Incident response (on-call service patrols).

Creating the operations improvements input files for use in HERS involved four steps: determining current operations deployment, determining future operations deployments, determining the cost of future operations investments, and determining the impacts of operations deployments. Different levels and types of deployments can be selected for an individual scenario.

Current Operations Deployments

To determine current operations deployments on the HPMS sample sections, data from the ITS Deployment Tracking Survey were used (http://www.itsdeployment.its.dot.gov/). These data were assigned to HPMS sample sections for each urbanized area using existing congestion and traffic levels on those sections as criteria.

Future Operations Deployments

For future ITS and operational deployments, projections were developed based on three alternatives. For the "Continuation of Existing Deployment Trends" alternative, existing deployments in urban areas were correlated with the congestion level and area population in order to predict on the basis of these factors where future deployments will occur. This alternative is reflected in the analyses presented in Chapters 7 and 8.

The other two alternatives are reflected in sensitivity analysis presented in Chapter 10. The "Aggressive Deployment" alternative assumes that deployment accelerates above existing trends and expands to more advanced strategies. Under this alternative, advanced in-vehicle navigation systems that provide real-time traveler information would supersede the current 511 systems. The "Full Immediate Deployment" alternative takes all of the deployments made in the first 20 years of the "Aggressive Deployment" alternative and assigns them to the first year. The "Full Immediate Deployment" alternative is intended to illustrate the maximum potential impact of the strategies and technologies modeled in HERS on highway operational performance. *Exhibit A-1* identifies the strategies employed in each alternative.

Operations Investment Costs

The unit costs for each deployment item were taken from the U.S. Department of Transportation's (DOT's) ITS Benefits Database and Unit Costs Database and supplemented with costs based on the ITS Deployment Analysis System (IDAS) model. Costs were broken down into initial capital costs and annual operating and maintenance costs. Additionally, costs were determined for building the basic infrastructure to support the equipment, as well as for the incremental costs per piece of equipment that is deployed.

Exhibit A-1 Types of Operations Strategies Included in Each Scenario

	Scenario	
Operations Strategy	**Continue Existing Trends**	**Aggressive and Full Immediate Deployment**
Arterial Management		
Signal Control	●	●
Emergency Vehicle Signal Preemption	●	●
Variable Message Signs	freeways only	freeways & arterials
Advanced Traveler Information		●
Freeway Management		
Ramp Metering	●	●
Variable Message Signs	●	●
511 Traveler Information	●	
Advanced Traveler Information		●
Integrated Corridor Mgmt.		●
Active Traffic Mgmt.		●
Incident Management (Freeways Only)		
Detection	●	●
Verification	●	●
Response	●	●

Source: Highway Economic Requirements System.

Impacts of Operations Deployments

Exhibit A-2 shows the estimated impacts of the different operations strategies considered in HERS. These effects include:

- Incident Management: Incident duration and the number of crash fatalities are reduced. Incident duration is used as a predictor variable in estimating incident delay in the HERS model.
- Signal Control: The effects of the different levels of signal control are directly considered in the HERS delay equations.
- Ramp Meters, VMS, VSL, Integrated Corridor Management, and Traveler Information: Delay adjustments are applied to the basic delay equations in HERS. VSL is assumed to have a small impact on fatalities as well.

Based on the current and future deployments and the impact relationships, an operations improvements input file was created for each of the two deployment scenarios. The file contains section identifiers, plus current and future values (for each of the four funding periods in the HERS analysis) for the following five fields:

- Incident Duration Factor
- Delay Reduction Factor
- Fatality Reduction Factor
- Signal Type Override
- Ramp Metering.

Exhibit A-2 Impacts of Operations Strategies in HERS

Operations Strategy	Impact Category	Impact
Arterial Management		
Signal Control	Congestion/Delay	Signal Density Factor = n(nx+2)/(n+2), where n = no. of signals per mile x = 1 for fixed time control 2/3 for traffic actuated control 1/3 for closed loop control 0 for real-time adaptive control/SCOOT/SCATS Signal Density Factor is used to compute zero-volume delay due to traffic signals
Electronic Roadway Monitoring	Congestion/Delay	Supporting deployment for corridor signal control (two highest levels) and traveler information
Emergency Vehicle Signal Preemption		
Variable Message Signs	Congestion/Delay	-0.5% incident delay
Freeway Management		
Ramp Metering		
Preset	Congestion/Delay	New delay = ((1 - 0.13)(original delay)) + 0.16 hrs per 1000 VMT
Traffic Actuated	Congestion/Delay	New delay = ((1 - 0.13)(original delay)) + 0.16 hrs per 1000 VMT
	Safety	-3% number of injuries and property damage only accidents
Electronic Roadway Monitoring	Congestion/Delay	Supporting deployment for ramp metering and traveler information
Variable Message Signs	Congestion/Delay	-0.5% incident delay
Integrated Corridor Management	Congestion/Delay	-7.5% total delay without VII, 12.5% total delay with VII
Active Traffic Management	Congestion/Delay Safety	-7.5% total delay -5% fatalities
Incident Management (Freeways Only)		
Detection Algorithm/ Free Cell	Incident Characteristics Safety	-4.5% incident duration -5% fatalities
Surveillance Cameras	Incident Characteristics Safety	-4.5% incident duration -5% fatalities
On-Call Service Patrols		
Typical	Incident Characteristics Safety	-25% incident duration -10% fatalities
Aggressive	Incident Characteristics Safety	-35% incident duration -10% fatalities
All Combined	Incident Characteristics Safety	Multiplicative reduction -10% fatalities
Traveler Information		
511 Only	Congestion/Delay	-1.5% total delay, rural only
Advanced Traveler Information (VII-enabled)	Congestion/Delay	-3% total delay, all highways

Source: Highway Economic Requirements System.

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HERS Improvement Costs

For the 2004 C&P Report, significant changes were made to the structure of the HERS improvement cost matrix, the assumed unit costs in that matrix, and the manner in which those values were applied. The improvement cost updates reflected in the 2004 C&P Report were based on highway project data from six States (see Appendix A of that report for more information) that, although adequate in most respects, were relatively thin in certain key areas. The 2004 update disaggregated the improvement cost values in urban areas by functional class and by urbanized area size. Three population groupings were used: small urban (populations of 5,000 to 49,999), small urbanized (populations of 50,000 to 200,000), and large urbanized (populations of more than 200,000). However, the data used to create values for the large urbanized areas did not include a significant number of projects in very large urbanized areas, and concerns were raised about the degree of construction cost comparability within this category.

For the 2006 C&P Report, additional project cost data were collected for large urbanized areas, rural mountainous regions, and high-cost capacity improvements. These data were used to update the HERS improvement cost matrix, which was also modified to include a new category for major urbanized areas with populations of more than 1 million. The HERS improvement cost matrix was adjusted further for the 2008 C&P Report based on some additional analysis of the data previously collected. For this report, no changes were made to the cost matrix except to adjust it for the change in the National Highway Construction Cost Index between 2006 and 2010.

Exhibit A-3 identifies the costs per lane mile assumed by HERS for different types of capital improvements. For rural areas, separate cost values are applied by terrain type and functional class, while costs are broken down for urban areas by population area size and type of highway. These costs are intended to reflect the typical values for these types of projects in 2010, and thus do not reflect the large variation in cost among projects of the same type, even in a given year. Such variation is evident in the project-level data on which these typical values are based, and are attributable to a number of location-specific factors. For example, the costs assumed for highway widening projects will be predicated on each section having a number of bridges typical for its length, but in reality some sections will have more bridges than other sections of equal length, which adds to costs. Among other factors that could make costs unusually high are complicated interchanges, major environmental issues, and/or other extreme engineering issues.

The values shown for adding a lane at “Normal Cost” reflect costs for projects where sufficient right-of-way is available or could be readily obtained to accommodate additional lanes. The values for adding lane equivalents at “High Cost” are intended to reflect situations in which conventional widening is not feasible and alternative approaches are required in order to add capacity to a given corridor. Such alternatives include the construction of parallel facilities, double-decking, tunneling, or the purchase of extremely expensive right-of-way. HERS models these lane equivalents as though they are part of existing highways, but some of this capacity could come in the form of new highways or investment in other modes of transportation.

Allocating HERS Results Among Improvement Types

Highway capital expenditures can be divided among three types of improvements: system rehabilitation, system expansion, and system enhancements (see Chapters 6 and 7 for definitions and discussion). All improvements selected by HERS that do not add lanes to a facility are classified as part of system rehabilitation, and highway projects that add lanes to a facility normally include resurfacing or reconstructing the existing lanes. HERS therefore splits the costs of such projects between system rehabilitation and system expansion.

Exhibit A-3 Typical Costs per Lane Mile Assumed in HERS, by Type of Improvement

(Thousands of 2010 Dollars per Lane Mile)

Category	Reconstruct and Widen Lane	Reconstruct Existing Lane	Resurface and Widen Lane	Resurface Existing Lane	Improve Shoulder	Add Lane, Normal Cost	Add Lane, Equivalent High Cost	New Alignment, Normal	New Alignment, High
Rural									
Interstate									
Flat	$1,409	$920	$797	$327	$61	$1,811	$2,510	$2,510	$2,510
Rolling	$1,579	$944	$918	$348	$100	$1,963	$3,177	$3,177	$3,177
Mountainous	$2,994	$2,067	$1,521	$515	$210	$6,113	$7,156	$7,156	$7,156
Other Principal Arterial									
Flat	$1,100	$737	$665	$262	$41	$1,451	$2,076	$2,076	$2,076
Rolling	$1,242	$757	$756	$292	$68	$1,553	$2,507	$2,507	$2,507
Mountainous	$2,413	$1,705	$1,465	$412	$89	$5,483	$6,314	$6,314	$6,314
Minor Arterial									
Flat	$1,006	$647	$620	$232	$38	$1,318	$1,851	$1,851	$1,851
Rolling	$1,215	$716	$771	$250	$70	$1,511	$2,384	$2,384	$2,384
Mountainous	$2,018	$1,323	$1,465	$343	$159	$4,629	$5,555	$5,555	$5,555
Major Collector									
Flat	$1,060	$685	$640	$237	$49	$1,370	$1,850	$1,850	$1,850
Rolling	$1,160	$696	$720	$252	$66	$1,399	$2,277	$2,277	$2,277
Mountainous	$1,758	$1,089	$1,048	$343	$101	$2,963	$3,870	$3,870	$3,870
Urban									
Freeway/Expressway/Interstate									
Small Urban	$2,297	$1,591	$1,810	$386	$71	$2,882	$9,434	$3,884	$13,259
Small Urbanized	$2,469	$1,605	$1,873	$457	$94	$3,170	$10,346	$5,236	$17,873
Large Urbanized	$3,938	$2,626	$2,900	$613	$354	$5,270	$17,676	$7,679	$26,216
Major Urbanized	$7,877	$5,253	$5,629	$1,015	$707	$10,540	$43,953	$15,359	$58,755
Other Principal Arterial									
Small Urban	$2,002	$1,351	$1,657	$324	$72	$2,450	$8,002	$3,062	$10,451
Small Urbanized	$2,142	$1,368	$1,732	$383	$96	$2,654	$8,702	$3,778	$12,895
Large Urbanized	$3,060	$2,005	$2,534	$481	$309	$3,884	$12,977	$5,186	$17,702
Major Urbanized	$6,120	$4,009	$5,068	$777	$617	$7,768	$30,113	$10,372	$44,897
Minor Arterial/Collector									
Small Urban	$1,475	$1,021	$1,253	$237	$52	$1,809	$5,860	$2,209	$7,542
Small Urbanized	$1,546	$1,032	$1,265	$269	$64	$1,906	$6,194	$2,711	$9,254
Large Urbanized	$2,081	$1,380	$1,729	$331	$173	$2,643	$8,774	$3,528	$12,042
Major Urbanized	$4,162	$2,761	$2,616	$550	$347	$5,285	$30,113	$7,056	$37,264

Source: Highway Economic Requirements System.

Costs of Air Pollutant Emissions

Greenhouse Gas Emissions

Road traffic generates an appreciable share of anthropogenic emissions of greenhouse gases (GHG). In the United States, passenger vehicles alone account for roughly 20 percent of emissions of carbon dioxide, and CO_2 emissions account for about 95 percent of the total global warming potential from all U.S. emissions of GHGs. In line with carbon dioxide emissions being the dominant concern relating to global warming, the HERS model has included a capability for quantifying and costing these emissions starting with the version of the model used for the 2010 C&P Report.

The quantification of CO_2 emissions from motor vehicle traffic is based on the amounts of gasoline and diesel fuel consumed (alternative fuels have yet to be incorporated into the model). Emissions directly from vehicles amount to 8,852 grams of CO_2 per gallon of gasoline consumed, and 10,239 grams per gallon of diesel fuel.[2] These are often referred to as tailpipe emissions, because they result from the fuel combustion process in motor vehicles' engines. In addition to these direct emissions, the fuel production and distribution processes produce CO_2 emissions as well, which are often referred to as upstream emissions. HERS allows users of the model the option of adding these upstream emissions, about which there is greater quantitative uncertainty, to its estimates of direct or tailpipe CO_2 emissions. HERS' estimates of upstream emissions are 2,072 grams of CO_2 per gallon of gasoline consumed, and 2,105 grams CO_2 per gallon of diesel.

HERS uses these estimates of CO_2 emissions per gallon of fuel consumed to convert vehicles' fuel consumption rates to CO_2 emissions per vehicle mile. The resulting estimates of CO_2 emissions per vehicle mile are then converted to dollar costs using estimates of climate-related economic damages caused by CO_2 emissions. A recent study by a Federal interagency working group (Interagency Working Group on Social Cost of Carbon 2010) estimated the costs to society from future climate-related economic damages caused by incremental CO_2 emissions. The group's estimates of this social cost of carbon were intended to include, at a minimum, the monetized impacts of emissions-induced climate change on net agricultural productivity, on human health, on property damages from increased flood risk, and on the value of ecosystem services. Low, medium, and high estimates of the social cost per metric ton of carbon were formed for each year from 2010 through 2050 using alternative discount rates. All estimates were originally reported in 2007 dollars.

The analyses presented in this report have used the medium estimates, and updated them to 2010 dollars using the gross domestic product price deflator (as was done in a recent analysis of corporate average fuel economy standards conducted by the National Highway Traffic Safety Administration). The adjusted values of CO_2 damage costs increase annually from $22.22 per metric ton in 2010 and reach $34.06 by 2030, the final year for which this report projects highway conditions and performance. For use as HERS inputs, the values were averaged to produce estimates of CO_2 damage costs for each 5-year HERS funding period. At the same time, however, vehicles' fuel consumption rates—and, thus, the rates at which they emit CO_2—are projected to decline in the future as the more fuel-efficient models required by Federal regulations replace older vehicles being retired from the fleet. On balance, CO_2 damage costs per vehicle mile under given driving conditions are projected to increase from 2010 to 2030, by about 15 percent for two-axle vehicles and about 28 percent for trucks with three or more axles.

Emissions of Criteria Air Pollutants

For the 2013 C&P Report, FHWA conducted new research to enhance and update HERS' procedures for estimating economic damage costs from motor vehicle emissions of criteria air pollutants or their chemical precursors: carbon monoxide, volatile organic compounds, nitrogen oxides, sulfur dioxide, and fine particulate matter.[3] These enhanced procedures and updated values of emission damage costs replace those previously used in HERS, which were originally documented in the 2005 HERS-ST Technical Report and previously updated as described in earlier editions of the C&P report.

HERS estimates of economic damages from vehicle emissions of air pollutants were updated by first estimating new emission rates—measured in mass per vehicle-mile of travel—for criteria pollutants and their precursors. These updated estimates were developed using the U.S. Environmental Protection Agency's (EPA's) recently issued Motor Vehicle Emission Simulator (MOVES) model. Average emissions per vehicle-mile of each pollutant vary among the roadway functional classes used in HERS because the typical mix of vehicles operating on each functional class varies and different types of vehicles emit these pollutants at different rates per vehicle mile. MOVES's emission rates also vary with travel speed and other driving conditions that affect vehicles' power output.

Repeated runs of the MOVES model were conducted to develop a schedule of average emissions per vehicle mile of each pollutant by travel speed for each roadway functional class during the midpoint year of each 5-year funding period used by HERS. Because MOVES utilizes different roadway classes than HERS, the most appropriate MOVES roadway class was used to represent each HERS functional class.

HERS combines these schedules of average emissions per vehicle mile for different pollutants with estimates of the average dollar cost of health damages caused per unit mass of each pollutant to calculate damage costs per vehicle mile for each pollutant. The dollar costs per unit of each pollutant used in HERS were updated using estimates for the years 2015, 2020, 2030, and 2040 supplied by EPA; these were interpolated to produce estimates for the midpoint of each 5-year funding period.[4] HERS then adds the estimates of damage costs for individual pollutants together to calculate total air-pollution-related costs per vehicle mile at different speeds. This process resulted in updated schedules of the average dollar cost of air-pollution-related damages per vehicle mile by speed for each HERS functional class and funding period.

Motor vehicles emission rates for each criteria pollutant are projected to decline significantly in the future as new vehicles that meet more stringent emissions standards gradually replace older models in the vehicle fleet. At the same time, however, EPA projects that economic damage costs per unit of each criteria air pollutant (except carbon monoxide) will increase rapidly over time. On balance, damage costs from vehicle emissions of criteria air pollutants are projected to decline by approximately 50 percent from the present through 2030 for four-tire vehicles operating on each HERS functional class, and by 80 to 90 percent for single-unit and combination trucks.

Effects on HERS Results

Potential improvement projects evaluated by HERS can affect air pollution and CO_2 damage costs by increasing the volume of travel on a section during future funding periods, as well as by increasing the average speed of travel on that section. Higher travel volumes invariably increase emissions and damage costs, but emission and fuel consumption rates are more complex functions of travel speeds, so increasing travel speed on a sample section can cause air pollution and CO_2 damage costs to either increase or decline. Since the speed-mediated effect is often to reduce emissions, the overall effect of an improvement project on air pollution or CO_2 damage costs can go either way. Net reductions in air pollution costs represent one component of the benefits from a potential improvement to a HERS sample section, while net increases represent one component of the costs (disbenefits).

Valuation of Travel Time Savings

New research was conducted to update estimates of the value of time in HERS for use in this edition of the C&P report. Estimates of the value of time in HERS are disaggregated by type of travel (i.e., personal and business) and type of vehicle (i.e., small auto, medium auto, four-tire truck, six-tire truck, three- and four-axle trucks, four-axle combination trucks, and combination trucks with five or more axles). Values of time for both personal and business travel are specified as functions of the value of time per person hour and average vehicle occupancy (i.e., representing the sum of personal travel costs across vehicle occupants); the value of time for business travel is also a function of vehicle capital costs and the value of cargo (for combination trucks capable of carrying significant payloads). For each vehicle type, the estimate of the value of time is the weighted average across personal and business travel value of time estimates (with no personal travel represented within six-tire trucks and combination trucks).

Exhibit A-4 shows the values for each of the components of the value of travel time savings, including the aggregate cost of travel for 2010 and 2008. The updating of the values to 2010 was more comprehensive than that for 2008, and the resulting estimates were more reliable. Values for 2010 were estimated using recent data, whereas values for 2008 were based on estimates for an earlier reference year that varied across

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Exhibit A-4 Estimated 2010 Values of Travel Time by Vehicle Type

2010 Travel Time Cost Elements	Travel Type	Small Auto	Medium Auto	4-Tire Truck	6-Tire Truck	3- and 4-Axle Truck	4-Axle Combination	5- or-More-Axle Combination
Value of Time per Person Hour	Business	$23.98	$23.98	$23.98	$23.98	$22.98	$22.98	$22.98
Average Vehicle Occupancy	Business	1.04	1.04	1.04	1.01	1.01	1.02	1.02
Vehicle Capital Cost per Vehicle	Business	$2.79	$3.42	$4.41	$6.22	$8.97	$8.05	$7.33
Inventory Value of Cargo	Business	--	--	--	--	--	$0.77	$0.77
Value of Time per Vehicle Hour	Subtotal	$27.73	$28.35	$29.46	$30.47	$32.23	$32.17	$31.44
Value of Time per Person Hour	Personal	$11.89	$11.89	$11.89	$11.89	$11.89	--	--
Average Vehicle Occupancy	Personal	1.38	1.38	1.61	1.61	20.20	--	--
Value of Time per Vehicle Hour	Subtotal	$16.35	$16.35	$19.16	$19.16	$272.03	--	--
Share of Personal Travel (% Vehicle Miles)		95.2%	95.2%	94.3%	0.0%	11.1%	0.0%	0.0%
2010	**Total**	**$16.89**	**$16.92**	**$19.75**	**$30.47**	**$58.80**	**$32.17**	**$31.44**
2008	**Total**	**$20.96**	**$21.00**	**$24.51**	**$29.88**	**$34.35**	**$38.32**	**$38.00**

Source: U.S. DOT Revised Guidance on the Value of Travel Time in Economic Analysis (September 28, 2011) and internal DOT estimates.

the elements in the calculations. For average vehicle occupancy and the business-purpose share of travel in four-tire vehicles, pre-2002 estimates were used. For monetary elements, reference-year estimates were updated using a relevant price deflator. For example, the entry for vehicle capital cost was updated from a 1995 reference year to 2008 using a measure of the change in average price of new motor vehicles during that period.

The value of travel time is estimated to be lower in 2010 than in 2008 for all vehicle types except six-tire trucks and the three- or four-axle vehicles. The value of travel time for six-tire trucks increased slightly because the new methodology increased the vehicle capital cost component. The value of travel time for three- to four-axle trucks increased substantially because the new methodology recognizes that some of these vehicles are actually buses, which have more occupants than trucks. Values for the other vehicle types have declined in 2010 compared to 2008 because of changes in methodology and data sources.

The value of time per person hour used in this edition follows the U.S. DOT's Revised Guidance on the Value of Travel Time in Economic Analysis, 2011. For personal travel that is local, the guidance recommends taking 50 percent of median household income divided by 2,080, which is the annual total hours worked by someone employed full-time (40 hours per week) and full-year (52 weeks). Although the guidance recommends upping this percentage to 70 percent for personal travel that is intercity, data with which to apportion personal travel between local and intercity trips is lacking. As a result, the HERS practice has been to value all personal travel following U.S. DOT recommendation for valuing personal travel that is local. For business travel, each hour is valued at the median nationwide gross wage plus fringe benefits, except for travel in trucks with three or more axles, for which the average truck driver wage is used.

Vehicle occupancy data was updated using the 2009 National Household Travel Survey (NHTS) for personal vehicles and the road freight inspection data from the Freight Motor carriers Safety Administration for freight. The estimates of average vehicle occupancy are overall lower for 2010 than for 2008. The decrease is from 1.15 to 1.04 for autos and from 1.12 to 1.02 for combination trucks. The recognition that some of the vehicles in the three- to four-axle truck category are actually buses increased average vehicle occupancy for that category significantly; although buses account for about 11 percent of the VMT of the vehicles classified as three- to four-axle trucks, they carry an average of 21.2 occupants including the driver.

The estimates of vehicle capital cost include the costs of interest and time-related deprecation, based on a 7-percent real discount rate. Time-related depreciation is based on the decline in vehicle value after the first five years of vehicle life (from the Consumer Reports Depreciation Calculator) net of the portion of this decline attributable to mileage (from HERS model calculations). The residual is the portion of depreciation that is time-related, due to vehicle aging. Data sources for the estimation of vehicle capital costs included the Energy Information Administration's Annual Energy Outlook, the 2009 NHTS, and 2002 Vehicle Inventory and Use Survey. The estimates of vehicle capital cost have increased in 2010 relative to 2008 for autos and small trucks and declined for trucks with three or more axles. The estimated value of cargo declined from $0.82 per hour in 2008 to $0.77 per hour in 2010. The inventory value of cargo represents the hourly financial carrying cost of holding inventory in transit. The estimate of the inventory value of cargo was found by assuming an interest rate of 7 percent and vehicle use of 2,000 hours per year, and applying these values to estimates of average weight of truck cargo (44,800 pounds, as calculated using the 2007 Commodity Flow Survey from the Bureau of Transportation Statistics) and average shipment value per pound (as calculated from the total value of shipments and total ton-miles carried by truck, also from the 2007 Commodity Flow Survey), with prices adjusted to 2010 dollars.

Endnotes

[1] The VII program at U.S. DOT has evolved into the Connected Vehicle Program: http://www.its.dot.gov/connected_vehicle/connected_vehicle.htm. As of this writing, for HERS the strategy enabled by VII technologies is advanced traveler information. Additional strategies covered under the Connected Vehicle program have not been incorporated.

[2] The chemical properties of fuels were obtained from Wang, M.Q., GREET 1.5 — Transportation Fuel-Cycle Model: Volume 1, Methodology, Use, and Results, ANL/ESD-39, Vol.1, Center for Transportation Research, Argonne National Laboratory, Argonne, Ill., August 1999, Table 3.3, p. 25 (available at http://greet.es.anl.gov/index.php?content=publications&by=date&order=up#Technical_Publications).

[3] Fine particulate matter now includes only particles up to 2.5 microns in diameter and is often referred to as PM2.5 for that reason. This revised definition excludes most or all components of road dust and particles produced by brake and tire wear. The main components of PM2.5 are sulfate, nitrate, and other particles formed by chemical reactions in the atmosphere from gaseous tailpipe emissions.

[4] For a description of these estimated damage costs, see: U.S. EPA and National Highway Traffic Safety Administration, Joint Technical Support Document, Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, August 2012, pp. 4-42 to 4-48 (available at http://www.nhtsa.gov/fuel-economy).

APPENDIX B

Bridge Investment Analysis Methodology

Bridge Investment Analysis Methodology

The National Bridge Investment Analysis System (NBIAS) was developed for assessing national bridge investment needs and the trade-off between funding and performance. NBIAS, first introduced in the 1999 C&P Report, is used to model investments in bridge repair, rehabilitation, and functional improvements. Over time, the system has been used increasingly as an essential decision support tool for analyzing policy and providing information to the U.S. Congress.

The NBIAS is based on an analytical framework similar to that used in the Pontis bridge program first developed by the Federal Highway Administration (FHWA) in 1992 and subsequently taken over by the American Association of State Highway and Transportation Officials (AASHTO). It incorporates economic forecasting analysis tools to project the multiyear funding needs required to meet user-selected performance metrics over the length of a user-specified performance period. The NBIAS is modified to work with bridge condition as reported by the States for the National Bridge Inspection System as well as the element/condition State inspection regime used in Pontis. The NBIAS combines statistical models with engineering judgment and heuristic rules to synthesize representative condition units so that they can be defined and manipulated using the same structure of condition states, actions, deterioration, costs, and effectiveness probabilities used in Pontis, making them compatible with Pontis' predictive models and analytical routines. NBIAS extends the Pontis element model by introducing the climate zone dimension into the stratification scheme and adding user cost components into the cost model. Effective in version 4.0 (2011), NBIAS also features an enhanced element optimization model that integrates selected maintenance policies.

General Methodology

Using linear programming optimization, NBIAS generates a set of prototype maintenance policies for defined subsets of the Nation's bridge inventory. Models of element deterioration, feasible actions, and the cost and effectiveness of those actions are incorporated as major inputs for each subset of the inventory. For functional deficiencies and improvements, NBIAS uses a model similar to the bridge level of service standards and user cost models of Pontis augmented by a bridge improvement model developed by the Florida Department of Transportation (DOT).

With a set of synthesized projects developed from the maintenance and functional improvement models, NBIAS calculates a trade-off structure showing the effect of hypothetical funding levels on each of more than 200 performance measures. For this analysis, it utilizes an adaptation of an incremental benefit-cost model with a graphical output showing the trade-off between funding and performance. To estimate functional improvement needs, NBIAS applies a set of improvement standards and costs, which can be modified by the user, to each bridge in the National Bridge Inventory (NBI). The system uses the available NBI data to predict detailed structural element data for each bridge. The system measures repair and rehabilitation needs at the bridge element level using the Markov decision model and then applies the obtained maintenance strategy, along with the improvement model, to each individual bridge.

The replacement costs for structures are determined based on State-reported values provided by the FHWA. Improvement costs are based on default costs from Pontis adjusted to account for inflation. In evaluating functional improvement needs and repair and rehabilitation needs, the system uses a set of unit costs of different improvement and preservation actions. State-specific cost adjustment factors are applied to the unit costs.

Determining Functional Improvement Needs

The standards for functional improvement include standards for lane widths, shoulder width, load ratings, and clearances (vertical and horizontal). The NBIAS includes a set of standards by functional class and additional standards derived from Sufficiency Rating calculations, as well as those prescribed by the models developed by Florida DOT.

The standards used in NBIAS initially were set to be the same as those specified by default in Pontis, which were established as an early effort to define level of service standards for AASHTO. The standards used in the previous editions of the C&P report were reviewed and compared with design standards in the AASHTO Green Book, and adjustments were made where warranted. A revised set of standards has subsequently been added that triggers consideration of a functional improvement whenever there is a deduction in Sufficiency Rating as a result of a road width, load rating, or clearances. The adoption of the Florida improvement model allowed for further fine tuning of the analysis logic of functional needs.

The NBIAS determines needs for the following types of bridge functional improvements: widening existing bridge lanes, raising bridges to increase vertical clearances, and strengthening bridges to increase load-carrying capacity. Functional improvement needs are determined by applying user-specified standards to the existing bridge inventory, subject to benefit-cost considerations. For instance, a need to raise a bridge will be identified if the vertical clearance under the bridge fails to meet the specified standard and if the stream of discounted increased cost of diverting commercial vehicles around the bridge exceeds the cost of improving the bridge.

If functional improvement is infeasible due to the bridge design or impractical because of its inferior structural condition, then the replacement need for the bridge is determined. Replacement need may also be identified if a user-specified replacement rule is triggered. For example, it is possible to introduce in NBIAS one or more replacement rules based on the threshold values of age, Sufficiency Rating, and Health Index.

Because the benefit predicted for a functional improvement increases proportionately with the amount of traffic, the determination of whether a functional improvement is justified and the amount of benefit from the improvement is heavily dependent upon predicted traffic. In the current version of NBIAS, traffic predictions are made for each year in an analysis period based on NBI data. The NBIAS allows the user to apply either linear or exponential traffic growth projections. Linear growth was selected for this edition of the C&P report, consistent with the assumption used in the Highway Economic Requirements System (HERS). When NBIAS selects a structure for replacement, the cost of the replacement is based on the number of lanes on the existing bridge. The cost of adding lanes to satisfy increased capacity demands is not included in the cost to construct the replacement structure. Additional costs for expanding bridges to meet increased capacity demands are included in the cost to construct a lane-mile of highway used in the HERS model.

Determining Repair and Rehabilitation Needs

To determine repair and rehabilitation needs, NBIAS predicts the elements that exist on each bridge in the U.S. bridge inventory and applies a set of deterioration and cost models to the existing bridge inventory. This allows NBIAS to determine the optimal preservation actions for maintaining the bridge inventory in a state of good repair while minimizing user and agency costs.

Predicting Bridge Element Composition

The NBIAS analytical approach relies on structural element data not available in the NBI. To develop this data, NBIAS uses a set of Synthesis, Quantity, and Condition (SQC) models to predict the elements that exist on each bridge in the NBI and the condition of those elements.

The synthesis part of the SQC model is implemented as the decision tree, in which the choice of the elements for a bridge is dictated by its design, material, and several other characteristics available in the NBI. Element quantities are evaluated based on the geometric dimensions of the bridge, its design, and material. The condition of the synthesized elements is modeled in the form of percentage-based distribution of element quantities across condition states. Such distributions are evaluated based on the structural ratings (superstructure, substructure, and deck) of the bridge to which the statistically tabulated lookup data and Monte Carlo simulation are applied.

The current version of NBIAS has the capability to accept the direct import of structural element data where these data are available, but this capability was not used for the development of this report. While most of the States now routinely collect such data on State-owned bridges as part of the bridge inspection process, these data are not currently part of the NBI data set.

MAP-21 requires the use of element-level data to analyze the performance of the bridges on the National Highway System (NHS). All other bridges will have the minimum data recorded and will require element-level data to be generated. Therefore, bridges on the NHS with detailed data will be combined with bridges with generated element data. This will require NBIAS to conduct analysis using a database containing bridges with detailed element information and bridges with generated detained information.

Calculating Deterioration Rates

The NBIAS takes a probabilistic approach to modeling bridge deterioration based on techniques first developed for Pontis. In the system, deterioration rates are specified for each bridge element through a set of transition probabilities that specify the likelihood of progression from one condition state to another over time. For each element, deterioration probability rates vary across nine climate zones.

Forming of the Optimal Preservation Policy

The policy of maintenance, repair, and rehabilitation (MR&R) of NBIAS is generated with the help of two optimization models: long-term and short-term. The long-term model is formulated as a linear problem with the objective of keeping the element population in a steady-state condition that requires the minimum cost to maintain. The short-term model, not being concerned with the steady state, seeks to find such prescription of remedial actions for condition states that minimize the subsequent costs of the actions including the discounted future costs. The short-term model of MR&R is implemented as the Markov Decision Model solved as a linear programming problem.

In the previous versions of NBIAS, only one MR&R strategy was available. In the course of the development of the NBIAS version 4.0, a study was conducted to develop alternative MR&R models. The result was the development of three additional MR&R strategies reflecting more diverse approaches to the maintenance of a bridge network.

Minimize MR&R Costs

This strategy involves identifying and implementing a pattern of MR&R improvements that minimizes MR&R spending. This model was adopted from Pontis, and used for the NBIAS analyses presented in all previous editions of the C&P report. This strategy is intended to prevent a catastrophic decrease in bridge network performance rather than to maintain or improve the overall condition of the bridge network. Some Pontis users and participants on expert peer review panels for NBIAS had raised concerns that this strategy was not consistent with typical bridge management strategies, and that following such a strategy may advance the point in time when a bridge would require replacement than might be the case if a more aggressive MR&R approach were utilized.

One of the side effects of having initially built this strategy as the only MR&R option in NBIAS was that most measures of bridge performance (such as the health index or sufficiency rating) would always get worse over the 20-year analysis period, even if all the potential bridge improvements identified as NBIAS as cost-beneficial were implemented. The exception was the estimated backlog of bridge needs, which is why this report has focused on that metric in the past. The estimated backlog is affected by the MR&R strategy; assuming a less aggressive MR&R strategy reduces the estimate of the MR&R backlog but increases the estimate of the bridge replacement backlog, generally resulting in a higher combined backlog estimate.

Maximize Average Returns

This strategy seeks to maximize the degree of bridge system performance improved per dollar of MR&R expenditure. Following this strategy results in more MR&R spending than under the Minimize MR&R strategy, but still generally results in deterioration in bridge performance over time.

State of Good Repair

This strategy seeks to bring all bridges to a relatively high condition level that can be sustained via ongoing investment. MR&R investment is front-loaded under this strategy, as large MR&R investments would be required in the early years of the forecast period to improve bridge conditions, while smaller MR&R investments would be needed in the later years to sustain bridge conditions.

This strategy would be optimal from a theoretical perspective if sufficient funding were available to implement it, but the high level of investment funds required in the initial years would make it challenging to follow this strategy given real-world financial constraints.

Sustain Steady State

This strategy involves identifying and implementing a pattern of MR&R improvements that would reach and achieve an improved steady state in terms of overall bridge system conditions, without frontloading MR&R investment. Following this strategy results in more MR&R spending than under the Maximize Average Returns strategy, but less than under the State of Good Repair strategy.

This Sustain Steady State strategy appears to be more consistent with current bridge agency practices than the other three strategies considered by NBIAS, and has been adopted for use in the baseline analyses presented in Chapters 7 and 8 of this report.

Applying the Preservation Policy

Using transition probability data, together with information on preservation action costs and user costs for operating on deteriorated bridge decks, NBIAS applies the Markov decision model to determine the optimal set of repair and rehabilitation actions to take for each bridge element based on the element's condition. During the simulation process, the preservation policy is applied to each bridge in the NBI to determine bridge preservation work needed to minimize user and agency costs over time.

In analyzing potential improvement options, the NBIAS compares the cost of performing preservation work with the cost of completely replacing a bridge, to identify situations where replacement is more cost effective. If the physical condition of the bridge has deteriorated to the point where it is considered unsafe (where the threshold for such a determination is specified by the system user), the system may consider bridge replacement to be the only feasible alternative for the bridge.

APPENDIX C

Transit Investment Analysis Methodology

Transit Investment Analysis Methodology

The Transit Economic Requirements Model (TERM), an analytical tool developed by the Federal Transit Administration (FTA), forecasts transit capital investment needs over a 20-year period. Using a broad array of transit-related data and research including data on transit capital assets, current service levels and performance, projections of future travel demand, and a set of transit asset-specific condition decay relationships, the model generates the forecasts that appear in the biennial C&P report.

This appendix provides a brief technical overview of TERM and describes the various methodologies used to generate the estimates for the 2010 C&P Report.

Transit Economic Requirements Model

TERM forecasts the level of annual capital expenditures required to attain specific physical condition and performance targets within a 20-year period. These annual expenditure estimates cover the following types of investment needs: (1) asset preservation (rehabilitations and replacements); and (2) asset expansion to support projected ridership growth.

TERM Database

The capital needs forecasted by TERM rely on a broad range of input data and user-defined parameters. Gathered from local transit agencies and the National Transit Database (NTD), the input data are the foundation of the model's investment needs analysis, and include information on the quantity and value of the Nation's transit capital stock. The input data in TERM are used to draw an overall picture of the Nation's transit landscape; the most salient data tables that form the backbone of the TERM database are described below.

Asset Inventory Data Table

The asset inventory data table documents the asset holdings of the Nation's transit operators. Specifically, these records contain information on each asset's type, transit mode, age, and expected replacement cost. As the FTA does not directly measure the condition of transit assets, asset condition data are not maintained in this table. Instead, TERM uses asset decay relationships to estimate the current and future physical condition as required for each model run. These condition forecasts are then used to determine when each type of asset identified in the asset inventory table is due for either rehabilitation or replacement. The decay relationships are statistical equations that relate asset condition to asset age, maintenance, and utilization. The decay relations and how TERM estimates asset conditions are further explained later in this appendix.

The asset inventory data are derived from a variety of sources including the NTD, responses by local transit agencies to the FTA data requests, and special FTA studies. The asset inventory data table is the primary data source for the information used in TERM's forecast of preservation needs. Note that the FTA does not currently require agencies to report on all asset types (with the exception of data for revenue vehicles, these data are provided only when requested). Furthermore, the transit industry has no standards for collecting or recording such data. Because of this, TERM analyses must rely on asset inventory data in the format and level of detail as provided by those agencies that respond to the FTA's asset data requests. Hence, the accuracy and consistency of TERM's estimates of asset needs would benefit from the availability of consistent and ongoing reporting of local agency asset holdings, including those asset's types, ages, modes and replacement values.

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Urban Area Demographics Data Table

This data table stores demographic information on close to 500 large-, medium-, and small-sized urbanized areas as well as for 10 regional groupings of rural operators. Fundamental demographic data, such as current and anticipated population, in addition to more transit-oriented information, such as current levels of vehicle miles traveled (VMT) and transit passenger miles, are used by TERM to predict future transit asset expansion needs.

Agency-Mode Statistics Data Table

The agency-mode statistics table contains operations and maintenance (O&M) data on each of the individual modes operated by approximately 700 urbanized transit agencies and more than 1,000 rural operators. Specifically, the agency-mode data on annual ridership, passenger miles, operating and maintenance costs, mode speed, and average fare data are used by TERM to help assess current transit performance, future expansion needs, and the expected benefits from future capital investments in each agency-mode (both for preservation and expansion). All the data in this portion of the TERM database come from the most recently published NTD reporting year. Where reported separately, directly operated and contracted services are both merged into a single agency-mode within this table.

Asset Type Data Table

The asset type data table identifies approximately 500 different asset types utilized by the Nation's public transit systems in support of transit service delivery (either directly or indirectly). Each record in this table documents each asset's type, unit replacement costs, and the expected timing and cost of all life-cycle rehabilitation events. Some of the asset decay relationships used to estimate asset conditions are also included in this data table. The decay relationships—statistically estimated equations relating asset condition to asset age, maintenance, and utilization—are discussed more in the next section of this appendix.

Benefit-Cost Parameters Data Table

The benefit-cost parameters data table contains values used to evaluate the merit of different types of transit investments forecasted by TERM. Measures in the data table include transit rider values (e.g., value of time and links per trip), auto costs per VMT (e.g., congestion delay, emissions costs, and roadway wear), and auto user costs (e.g., automobile depreciation, insurance, fuel, maintenance, and daily parking costs).

Mode Types Data Table

The mode types data table provides generic data on all of the mode types used to support U.S. transit operations—including their average speed, average headway, and average fare—and estimates of transit riders' responsiveness to changes in fare levels. Similar data are included for non-transit modes, such as private automobile and taxi costs. The data in this table are used to support TERM's benefit-cost analysis.

The input tables described above form the foundation of TERM, but are not the sole source of information used when modeling investment forecasts. In combination with the input data, which are static—meaning that the model user does not manipulate them from one model run to the next—TERM contains user-defined parameters to facilitate its capital expenditure forecasts.

Investment Policy Parameters

As part of its investment needs analysis, TERM predicts the current and expected future physical condition of U.S. transit assets over a 20-year period. These condition forecasts are then used to determine when each of the individual assets identified in the asset inventory table are due for either rehabilitation or replacement. The investment policy parameters data table allows the model user to set the physical condition ratings at which rehabilitation or replacement investments are scheduled to take place (though the actual timing of rehabilitation and replacement events may be deferred if the analysis is budget constrained). Unique replacement condition thresholds may be chosen for the following asset categories: guideway elements,

facilities, systems, stations, and vehicles. For the 2010 C&P Report, all of TERM's replacement condition thresholds have been set to trigger asset replacement at condition 2.50 (under the **Sustain 2010 Spending scenario**, many of these replacements would be deferred due to insufficient funding capacity).

In addition to varying the replacement condition, users can also vary other key input assumptions intended to better reflect the circumstances under which existing assets are replaced and the varying cost impacts of those circumstances. For example, users can assume that existing assets are replaced under full service, partial service, or a service shut down. Users can also assume assets are replaced either by agency (force-account) or by contracted labor. Each of these affects the cost of asset replacement for rail assets.

Financial Parameters

TERM also includes two key financial parameters. First, the model allows the user to establish the rate of inflation used to escalate the cost of asset replacements for TERM's needs forecasts. Note that this feature is not used for the C&P report, which reports all needs in current dollars. Second, users can adjust the discount rate used for TERM's benefit-cost analysis.

Investment Categories

The data tables described above allow TERM to estimate different types of capital investments, including rehabilitation and replacement expenditures, expansion investments, and capital projects aimed at performance improvements. These three different investment categories are described below.

Asset Rehabilitation and Replacement Investments

TERM's asset rehabilitation and replacement forecasts are designed to estimate annual funding needs for the ongoing rehabilitation and replacement of the Nation's existing transit assets. Specifically, these needs include the normal replacement of assets reaching the end of their useful life, mid-life rehabilitations, and annual "capital expenditures" to cover the cost of smaller capital reinvestment amounts not included as part of asset replacement or rehabilitation activities.

To estimate continuing replacement and rehabilitation investments, TERM estimates the current and expected future physical condition of each transit asset identified in TERM's asset inventory for each year of the 20-year forecast. These projected condition values are then used to determine when individual assets will require rehabilitation or replacement. TERM also maintains an output record of this condition forecast to assess the impacts of alternate levels of capital reinvestment on asset conditions (both for individual assets and in aggregate). In TERM, the physical conditions of all assets are measured using a numeric scale of 5 through 1; see *Exhibit C-1* for a description of the scale.

TERM currently allows an asset to be rehabilitated up to five times throughout its life cycle before being replaced. During a life-cycle simulation, TERM records the cost and timing of each reinvestment event as a model output and adds it to the tally of national investment needs (provided they pass a benefit-cost test, if applied).

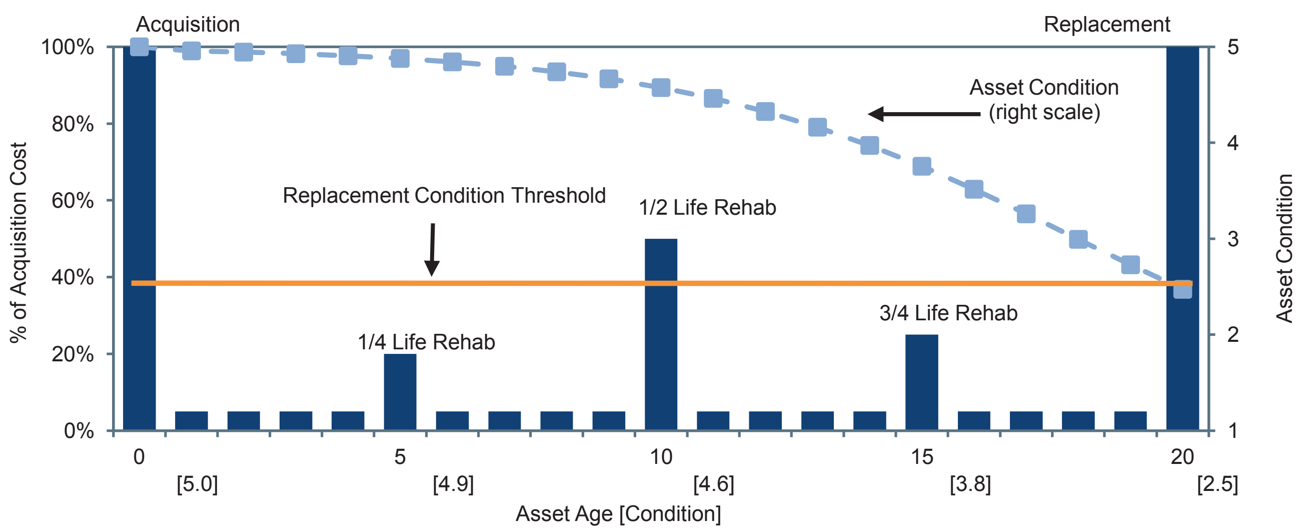
Exhibit C-1 Definitions of Transit Asset Conditions

Rating	Condition	Description
Excellent	4.8–5.0	No visible defects, near new condition.
Good	4.0–4.7	Some slightly defective or deteriorated components.
Adequate	3.0–3.9	Moderately defective or deteriorated components.
Marginal	2.0–2.9	Defective or deteriorated components in need of replacement.
Poor	1.0–1.9	Seriously damaged components in need of immediate repair.

Source: Transit Economic Requirements Model.

TERM's process of estimating rehabilitation and replacement needs is represented conceptually for a generic asset in *Exhibit C-2*. In this theoretical example, asset age is shown on the horizontal axis, the cost of life-cycle capital investments is shown on the left-vertical axis (as a percent of acquisition cost), and asset conditions are shown on the right-vertical axis. At the acquisition date, each asset is assigned an initial condition rating of 5, or "excellent," and the asset's initial purchase cost is represented by the tall vertical bar at the left of the chart. Over time, the asset's condition begins to decline in response to age and use, represented by the dotted line, requiring periodic lifecycle improvements including annual capital maintenance and periodic rehabilitation projects. Finally, the asset reaches the end of its useful life, defined in this example as a physical condition rating of 2.5, at which point the asset is retired and replaced.

Exhibit C-2 **Scale for Determining Asset Condition Over Time, From Acquisition to Replacement**



Asset Expansion Investments

In addition to devoting capital to the preservation of existing assets, most transit agencies invest in expansion assets to support ongoing growth in transit ridership. To simulate these expansion needs, TERM continually invests in new transit fleet capacity as required to maintain at current levels the ratio of peak vehicles to transit passenger miles. The rate of expansion is projected individually for each of the Nation's roughly 500 urbanized areas (e.g., based on the urbanized area's specific growth rate projections or historic rates of transit passenger mile growth) while the expansion needs are determined at the individual agency-mode level. TERM will not invest in expansion assets for agency-modes with current ridership per peak vehicle levels that are well below the national average (these agency modes can become eligible for expansion during a 20-year model run if there is sufficient projected growth in ridership for them to rise above the expansion investment threshold).

In addition to forecasting fleet expansion requirements to support the projected ridership increases, the model also forecasts expansion investments in other assets needed to support that fleet expansion. This includes investment in maintenance facilities and, in the case of rail systems, additional guideway miles including guideway structure, trackwork, stations, train control, and traction power systems. Like other investments forecast by the model, TERM can subject all asset expansion investments to a benefit-cost analysis. Finally, as TERM adds the cost of newly acquired vehicles and supporting infrastructure to its tally of investment needs, it also ensures that the cost of rehabilitating and replacing the new assets is accounted for during the 20-year period of analysis.

The rate of growth in transit passenger miles underlying these asset expansion investments have typically been based on growth rate projections obtained from a sample from the Nation's 20 to 30 largest Metropolitan Planning Organizations. For this edition of the C&P report, urbanized-area-specific historic growth rates have also been used. Note that if the *actual* growth rate that materializes in the future is less than the current *projected* rate of increase, then the level of expansion will be higher than that required to maintain current service and service quality will improve.

Asset Decay Curves

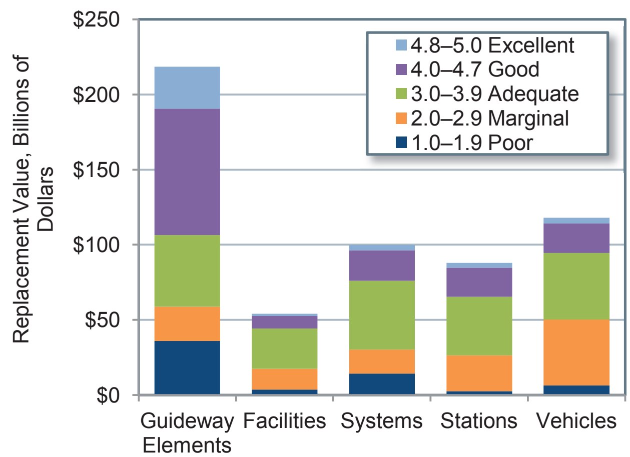
TERM asset decay curves were developed expressly for use within TERM and are comparable to asset decay curves used in other modes of transportation and bridge and pavement deterioration models. While the collection of asset condition data is not uncommon within the transit industry, TERM asset decay curves are believed to be the only such curves developed at a national level for transit assets. Most of the TERM key decay curves were developed using data collected by FTA at multiple U.S. transit properties specifically for this purpose.

TERM decay curves serve two primary functions: (1) to estimate the physical conditions of groups of transit assets and (2) to determine the timing of rehabilitation and replacement reinvestment.

Estimating Physical Conditions

One use of the decay curves is to estimate the current and future physical conditions of groups of transit assets. The groups can reflect all of the national transit assets or specific sub-sets, such as all assets for a specific mode. For example, the *Exhibit C-3* below presents a TERM analysis of the distribution of transit asset conditions at the national level as of 2010.

Exhibit C-3 **Distribution of Asset Physical Condition by Asset Type for All Modes**

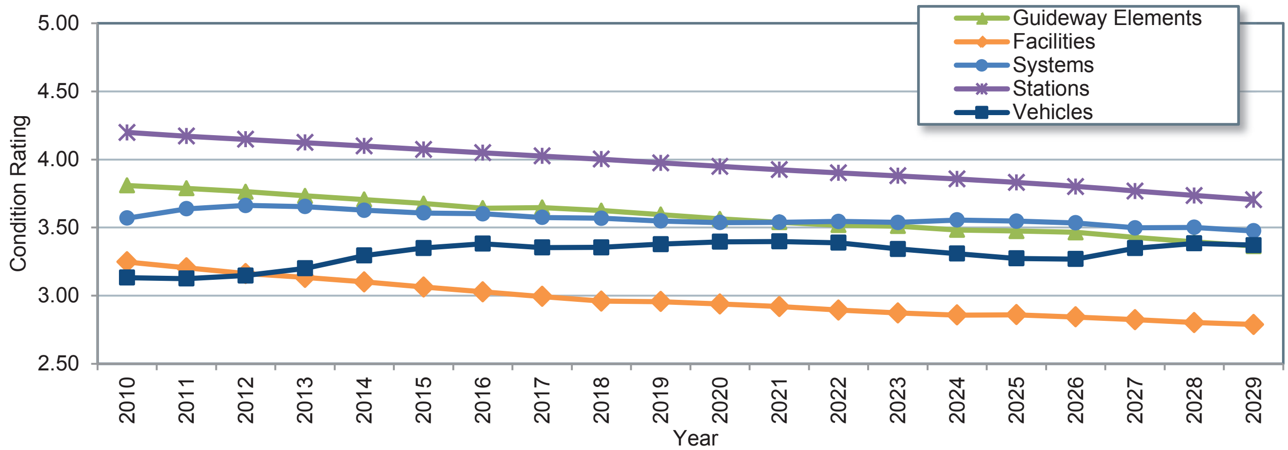


Source: Transit Economics Requirements Model.

This exhibit shows the proportion and replacement value of assets in each condition category (excellent, good, etc.) segmented by asset category. TERM produced this analysis by first using the decay curves to estimate the condition of individual assets identified in the inventory of the national transit assets and grouping these individual asset condition results by asset type.

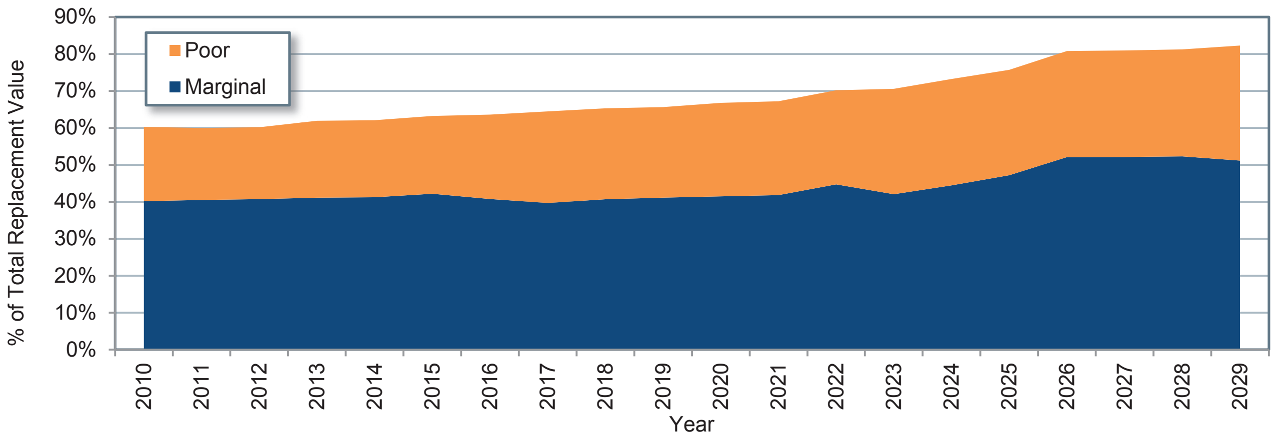
TERM also uses the decay curves to predict expected future asset conditions under differing capital reinvestment funding scenarios. An example of this type of analysis is presented below in *Exhibits* C4 and *C-5*, which present TERM forecasts of the future condition of the national transit assets assuming the national level of reinvestment remains unchanged. *Exhibit C-4* shows the future condition values estimated for each of the individual assets identified in the asset inventory (weighted by replacement value) to generate annual point estimates of average future conditions at the national level by asset category. *Exhibit C-5* presents a forecast of the proportion of assets in either marginal or poor condition, assuming limited reinvestment funding for a subset of the national transit assets.

Exhibit C-4 Weighted Average by Asset Category, 2010–2029



Source: TERM, Sustain 2010 Spending.

Exhibit C-5 Assets in Marginal or Poor Condition, 2010–2029



Source: TERM, Sustain 2010 Spending (Excludes Unreplaceable Assets).

Determine the Timing of Reinvestment

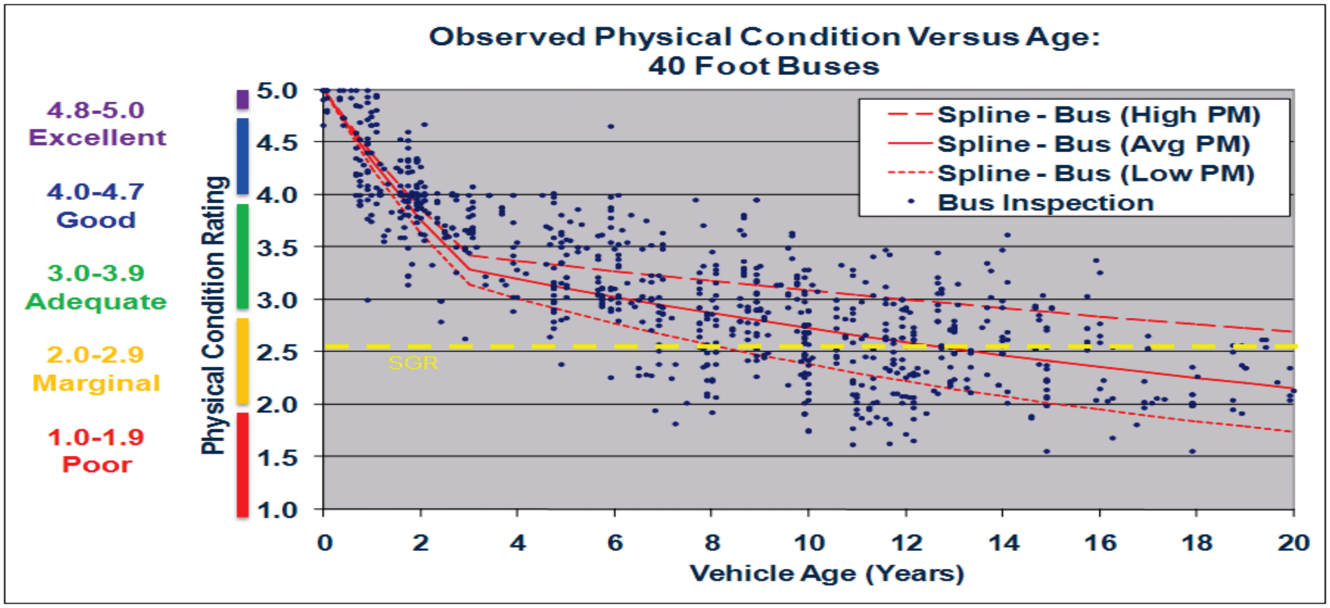
Another key use of the TERM asset decay curves is to determine when the individual assets identified in the asset inventory will require either rehabilitation or replacement, with the ultimate objective of estimating replacement needs and the size of the state of good repair (SGR) backlog. Over the 20-year period of analysis covered by a typical TERM simulation, the model uses the decay curves to continually monitor the declining condition of individual transit assets as they age. As an asset's estimated condition value falls below pre-defined threshold levels (known as "rehabilitation condition threshold" and "replacement condition threshold"), TERM will seek to rehabilitate or replace that asset accordingly. If sufficient funding is available to address the need, TERM will record this investment action as a need for the specific period in which it occurs. If insufficient funding remains to address a need, that need will be added to the SGR backlog. These rehabilitation and replacement condition thresholds are controlled by asset type and can be changed by the user. Some asset types, such as maintenance facilities, undergo periodic rehabilitation while others, such as radios, do not.

Development of Asset Decay Curves

Asset decay curves are statistically estimated mathematical formulas that rate the physical condition of transit assets on a numeric scale of 5 (excellent) to 1 (poor).

The majority of TERM decay curves are based on empirical condition data obtained from a broad sample of U.S. transit operators; hence, they are considered to be representative of transit asset decay processes at the national level. An example decay curve showing bus asset condition as a function of age and preventive maintenance based on observations of roughly 900 buses at 43 different transit operators is presented in *Exhibit C-6* below.

Exhibit C-6 **TERM Asset Decay Curve for 40-Foot Buses**



Source: FTA; empirical condition data obtained from a broad sample of U.S. transit operators.

Benefit-Cost Calculations

TERM uses a benefit-cost (B/C) module to assess which of a scenario's capital investments are cost effective and which are not. The purpose of this module is to identify and filter investments that are not cost effective from the tally of national transit capital needs. Specifically, TERM can filter all investments where the present value of investment costs exceeds investment benefits (B/C<1).

The TERM B/C module is a business case assessment of each agency-mode (e.g., "Metroville Bus" or "Urban City Rail") identified in the NTD. Rather than assessing the B/C for each individual investment need for each agency-mode (e.g., replacing a worn segment of track for Urban City Rail), the module compares the stream of future benefits arising from continued future operation for an entire agency-mode against all capital (rehab-replace and expansion) and operating costs required to keep that agency-mode in service. If the discounted stream of benefits exceeds the costs, then TERM includes that agency-mode's capital needs in the tally of national investment needs. If the net present value of that agency-mode investment is less than 1 (B/C<1), then TERM scales back these agency-mode needs until the benefits are equal to costs as discussed below.

In effect, the TERM B/C module conducts a system-wide business case analysis to determine if the value generated by an existing agency-mode is sufficient to warrant the projected cost to operate, maintain, and potentially expand that agency-mode. If an agency-mode does not pass this system-wide business case

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assessment, then TERM will not include some or all of that agency-mode's identified reinvestment needs in the tally of national investment needs. The benefits assessed in this analysis include user, agency, and social benefits of continued agency operations.

The specific calculations used by the TERM B/C module – comparing the stream of investment benefits for agency-mode "j" against the stream of ongoing costs, calculated over the TERM 20-year analysis horizon – is presented below in equation (1).

$$Benefit/Cost\ \ Ratio_{agency-mode\ j} = \tag{1}$$

$$\left\{ \frac{\sum_{t=1}^{20} \left\{ \left(\left(User,\ Agency\ \&Social\ Benefits_{j,t=0} \right) * \left(1 + TMP\,Growth_j \right)^t \right) / (1+i)^t \right\}}{\sum_{t=1}^{20} \left\{ \left(Replace\,Cost_{j,t} + Expansion\ \ Cost_{j,t} + \left(O\ \&\ M\,Costs_{j,t} * \left(1 + TPM\ \ Growth_j \right)^t \right) \right) / (1+i)^t \right\}} \right\}$$

Why Use a System-wide Business Case Approach?

TERM considers the cost-benefit of the entire agency rail investment versus simply considering the replacement of a single rail car. Costs and benefits are grouped into an aggregated investment evaluation and not evaluated at the level of individual asset investment actions (e.g., replacement of a segment of track) for two primary reasons: (1) lack of empirical benefits data, and (2) transit asset interrelationships.

<u>Lack of Empirical Benefits Data:</u> The marginal benefits of transit asset reinvestment are very poorly understood for some asset types (e.g., vehicles) to non-existent for others. Consider this example: replacement of an aging motor bus will generate benefits in the form of reduced maintenance costs, improved reliability (fewer in-service failures and delays) and improved rider comfort, and potentially increased ridership in response to these benefits. The magnitude of each of these benefits will be dependent on the age of the vehicle retired (with benefits increasing with increasing age of the vehicle being replaced). But what is the dollar value of these benefits? Despite the fact that transit buses are the most numerous of all transit assets and a primary component of most transit operations, the relationship between bus vehicle age and O&M cost, reliability, and the value of rider comfort is poorly understood (there are no industry standard metrics tying bus age to reliability and related agency costs). The availability of reinvestment benefits for other transit asset types is even more limited (perhaps with the exception of rail cars, where the understanding is comparable to that of bus vehicles).

<u>Transit Asset Interrelationships</u>: The absence of empirical data on the benefits of transit asset replacement is further compounded by both the large number of transit assets that must work together to support transit service and the high level of interrelatedness between many of these assets. Consider the example of a (1) rail car operating on (2) trackwork equipped with (3) train control circuits and (4) power supply (running through the track), all supported by (4) a central train control system and located on (5) a foundation such as, elevated structure, subway, retained embankment, etc.. This situation represents a system that is dependent on the ongoing operation of multiple interdependent assets, each with differing costs, life cycles and reinvestment needs – and yet totally interdependent of one another. Now consider the benefits of replacing a segment of track that has failed. The cost of replacement (thousands of dollars) is insignificant compared to the benefits derived from all the riders that depend on that rail line for transit service of maintaining system operations. The fallacy in making this comparison is that the rail line benefits are dependent on ongoing reinvestment in all components of that rail line (track, structures, control systems, electrification, vehicles, and stations) and not just from reinvestment in specific components.

Incremental Benefit-Cost Assessment

TERM's B/C module is designed to assess the benefits of incremental levels of reinvestment in each agency-mode in a three-step approach:

Step 1: TERM begins its benefit-cost assessment by considering the benefits derived from all of TERM's proposed capital investment actions for a given agency-mode – including all identified rehabilitation, replacement, and expansion investments. If the total stream of benefits from these investments exceeds the costs, then all assets for this agency-mode are assigned the same (passing) benefit-cost ratio. If not, then the B/C module proceeds to Step 2.

Step 2: Having "failed" the Step 1 B/C test, TERM repeats this B/C evaluation, but this time excludes all expansion investments. In effect, this test suggests that this agency-mode does not generate sufficient benefits to warrant expansion but may generate enough benefits to warrant full reinvestment. If the agency-mode passes this test, then all reinvestment actions are assigned the same, passing B/C ratio. Similarly, all expansion investments are assigned the same failing B/C ratio (as calculated in Step 1). If the agency-mode fails the Step 2 B/C test, the B/C module proceeds to Step 3.

Step 3: The Step 3 B/C test provides a more realistic assessment of agency-mode benefits. Under this test, it is assumed that agency-mode benefits exceed costs for at least some portion of that agency-mode's operations; hence, this portion of services is worth maintaining.

Investment Benefits

TERM's B/C module segments investment benefits into three groups of beneficiaries:

- Transit riders (user benefits)
- Transit operators
- Society.

Rider Benefits: By far the largest individual source of investment benefits (roughly 86% of total benefits) accrue to transit riders. Moreover, as assessed by TERM, these benefits are measured as the difference in total trip cost between a trip made via the agency-mode under analysis versus the agency-mode user's next best alternative. The total trip cost includes both out-of-pocket costs (e.g., transit fare, station parking fee) and value of time costs (including access time, wait time, and in-vehicle travel time).

Transit Agency Benefits: In general, the primary benefit to transit agencies of reinvestment in existing assets comes from the reduction in asset O&M costs. In addition to fewer asset repair requirements, this benefit also includes reductions of in-service failures (technically also a benefit to riders) and the associated in-service failures response costs (e.g., bus vehicle towing and substitution, bus for rail vehicle failures).

At present, none of these agency benefits is considered by TERM's B/C model. As noted above, there is little to no data to measure these cost savings. That said, there are some data on which to evaluate these benefits (mostly as related to fleet reinvestment and not available at the time the B/C module was developed). FTA could move to incorporate some of these benefits in future versions of TERM.

Societal Benefits: TERM assumes that investment in transit provides benefits to society by maintaining or expanding an alternative to travel by car. More specifically, reductions in vehicle miles traveled (VMT) made possible by the existence or expansion of transit assets is assumed to generate benefits to society. Some of these benefits may include reductions in highway congestion, air and noise pollution, greenhouse gases, energy consumption, and automobile accidents. TERM's B/C module does not consider any societal benefits beyond those related to reducing VMT (hence, benefits such as improved access to work, are not considered).

APPENDIX D

Crosscutting Investment Analysis Issues

Crosscutting Investment Analysis Issues

Appendix D of the 2010 C&P Report discussed limitations of the modeling and databases used for the report's analysis as well as possible remedies. Appendix D in this report updates that discussion with recent progress and plans. It further explores select issues that recent developments have made more relevant. The economic slow-down from which the Nation is now emerging has stimulated interest in the impacts of transportation investments on aggregate employment and on U.S. economic competitiveness—impacts which have always been difficult to measure. The increased policy emphasis at the U.S. Department of Transportation (DOT) on livability, sustainability, and maintenance of transportation assets in a state of good repair has likewise moved certain modeling challenges to the fore. The structure of the discussion in this appendix largely follows that of Appendix D in the 2010 C&P Report; readers can refer back to that report's appendix for discussion of the many issues that have not been revisited.

Conditions and Performance

Pavement Condition

In recent years, the Federal Highway Administration (FHWA) has used the International Roughness Index (IRI) to describe the condition of the Nation's pavements. The IRI is an objective measure and pavement roughness directly affects road users by influencing ride quality. The current pavement performance models in the Highway Economic Requirements System (HERS) use an alternative measure, the Present Serviceability Rating, which is strongly correlated with IRI. However, the models are somewhat out of date with respect to pavement design and to structural pavement problems that do not manifest themselves through roughness alone.

Enhanced Pavement Deterioration Models

In the last several years, research in the fields of pavement management, pavement design, and the collection of pavement distress data has resulted in the development of new pavement design formulas, improvements in data collection, and better approaches to monitoring highway pavement conditions. The development of a Mechanistic Empirical Pavement Design Guide (ME-PDG) formula was sponsored by the American Association of State Highway and Transportation Officials and the FHWA through the National Cooperative Highway Research Program.

Applying the ME-PDG pavement design formulas in the context of the HERS model presents several challenges. The ME-PDG formulas require an extensive amount of data for use in designing pavements for individual highway projects; collecting such information on a national basis for all Highway Performance Monitoring System (HPMS) sample sections (whether they are currently under consideration for improvement or not) would have placed an excessive reporting burden on the States that would not be warranted for conducting an aggregate national-level analysis of systemwide needs. Even if the necessary input data were readily available, applying the ME-PDG equations in their original form within the HERS model would have significantly impacted the run time for the model, making it impractical from a C&P report development perspective.

An evaluation of the components of the ME-PDG formulas was conducted to determine the minimum number of data items required to predict general pavement performance at an aggregate level that would be more appropriate for pavement performance analysis at the national level. Based on this evaluation, it was determined the number of additional data items required to be reported by State DOTs could be

limited from the more than 100 original ME-PDG inputs to less than 10. Some of the items needed related to date of construction, last rehabilitation/maintenance date, and pavement type; such items should be readily obtainable from project records. Other items vary with time and would need to be obtained through automated data collection and/or observation in the field, including pavement roughness (IRI), depth of rutting or faulting, amount of cracking present per mile (percent), and the total area of failure per mile (percent). In some cases, default values at the State level representing typical conditions or construction practices were deemed sufficient; this includes items such as dowel bar spacing and soil type. Based on feedback from a working group of State DOT representatives, it was determined that collecting this limited set of additional data items from States is feasible, particularly because many States routinely collect information of this nature as part of their own pavement management programs.

The evaluation of the ME-PDG's suitability for adaptation into the HERS model fed into the most recent formal reassessment of the HPMS. As a result, the HPMS was modified to begin collecting additional pavement information to support a set of simplified ME-PDG-based models in HERS. The simplified pavement deterioration equations have been added to the HERS model and initial testing has been conducted. However, the reporting of the new and revised pavement data items for 2010 HPMS highway sample sections by the States was not sufficiently complete to support full testing of the new pavement equations. Additional testing will be conducted on future HPMS submittals as States have time to better adapt to the revised HPMS reporting requirements. In addition, the underlying ME-PDG pavement design formulas have been revised subsequent to the versions originally adapted for use in HERS. The FHWA will be evaluating these ME-PDG revisions to determine the extent to which they would impact the simplified ME-PDG equations developed for HERS, and will adapt the simplified equations as necessary.

Preventive Maintenance Models

As discussed in Chapter 7, the investment scenarios estimated in this report are for capital expenditures only and do not include costs associated with preventive maintenance. However, the FHWA and State DOTs are paying increased attention to preventive maintenance strategies as a means of extending the useful life of pavement improvements. To the extent that such strategies are successful, they can reduce the need for capital improvements to address pavement condition deficiencies, an effect that the investment models should account for where possible. Future improvements to the HERS model based on these new data and equations should facilitate the evaluation of tradeoffs between more aggressive preventive maintenance strategies and capital improvements.

The FHWA has research underway to classify different types of State preventative maintenance strategies into broad groups with similar costs and impacts to make it feasible to simulate them within the HERS model framework. This research also involves the development of procedures for determining the optimal types and timing of preventive maintenance actions to be considered, for assessing the impacts of different types of actions on the remaining pavement service life and on future pavement performance, and for estimating the impacts of preventative maintenance actions on routine maintenance costs incurred by highway agencies and on the costs experienced by system users.

Transit Asset Reporting

The Transit Economic Requirements Model's (TERM's) assessment of transit capital needs for both asset preservation and service expansion rely heavily on data that document the asset holdings of the Nation's urban and rural transit operators. However, with the exception of agency passenger vehicle fleets, local transit operators receiving Federal transit funding have not been required to report asset inventory data documenting the types, quantities, ages, conditions, or replacement values of assets they use in support of transit service. Therefore, to obtain asset inventory data for use in TERM, the Federal Transit Administration (FTA) must periodically submit asset inventory data requests to the Nation's largest bus and rail operators and a sample of smaller operators. Given the absence of any standards for asset inventory recording or

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reporting, the response to these requests provides inventory data in a variety of formats and at varying levels of detail and quality. Moreover, the asset holdings of those agencies that either do not receive or do not effectively respond to these requests must be estimated (based on the asset composition and age distribution of agencies of comparable size).

This situation will be changing due to requirements in the 2012 surface transportation bill (Moving Ahead for Progress in the 21st Century [MAP-21]) for FTA grant recipients to report asset inventory and condition data to the National Transit Database (NTD). Work to roll out this new data collection is underway and FTA hopes to collect an initial round of asset inventory data when agencies report their 2013 data. These data will provide for significantly better estimates of long-term transit reinvestment needs and will ensure greater comparability of results across future editions of the C&P report and allow for establishment of meaningful performance goals and measures. Although this data collection effort is anticipated to start with the 2013 NTD reporting year, actual implementation will depend on transit agencies' response to the Federal Register Notice of Proposed Rulemaking and on the Office of Management and Budget's response to the Paperwork Reduction Act request.

Vehicle Operating Costs

Growing concerns about energy independence and the environmental costs of vehicle emissions have stimulated interest in the impacts of highway investments and policies on fuel consumption. Unfortunately, the modeling of the impacts on road fuel economy and, more generally, on vehicle operating costs is an area in which highway performance evaluation models have lagged. HERS, along with various other models (e.g., the FHWA's project evaluation tool, BCA.net), has relied primarily on decades-old evidence, including foreign evidence that is not easily generalized to U.S. scenarios. The HERS equations for vehicle operating cost are based on the model of vehicle operating costs developed in a 1982 study by the Texas Research and Development Foundation (TRDF) (Vehicle Operating Costs, Fuel Consumption, and Pavement Type and Condition Factors by J.P. Zaniewski et al., TRDF, June 1982, prepared for FHWA). For the impacts of pavement condition on vehicle operating costs, the study drew on the results of tests conducted in Brazil in the 1970s on pavements typically rougher than those on U.S. roads. For the impacts of vehicle speed on vehicle operating costs, the study relied on tests conducted on U.S. roads in the 1970s. Reflecting the limitations of the TRDF study, HERS does not fully allow for the effects of congestion delay on fuel consumption. These effects are sometimes conceptualized as stemming partly from a reduction in average speed and partly from an increase in speed variability due to stop-and-go driving conditions. The HERS model allows for the speed variability effect only on signalized roadways. A more complete account of this effect would also extend to stop-and-go conditions on unsignalized facilities and in work zones.

For each edition of the C&P report, the prices in HERS for vehicle operating inputs are updated to the base-year levels using the most suitable price indices available. Price indices specific to fuel and tires are available, but more general price indices are used for some of the other input categories (such as repair and maintenance), which causes some divergence between actual price levels and what HERS assumes. For fuel consumption, the HERS equations include efficiency factors that incorporate the percent changes over time in average vehicle fuel efficiency on U.S. highways. Because this adjustment only scales the equations without otherwise changing the parameters, it cannot capture fundamental changes over time in how vehicle speed and other factors affect fuel economy—for example, changes in the speed range at which fuel economy is highest.

To chart a course for improving the HERS treatment of vehicle operating costs, the FHWA has initiated a scoping study that generated a set of preliminary recommendations for improved modeling of fuel consumption. The recommended short-term option would make use of a vehicle fuel consumption simulation model, quite possibly VEHSIM, to develop relationships in HERS that would predict fuel economy on highway sections as a function of congestion levels, pavement roughness, and other section

characteristics. The longer-term and more expensive option would improve modeling accuracy, particularly for trucks, by: (1) expanding the set of vehicle drive cycles, which characterize at different levels of congestion a typical second-by-second speed trajectory over a short time cycle; and (2) providing a more comprehensive profile of the vehicle fleet for modeling fuel economy at the fleet level. The vehicle simulation models have been developed to facilitate the design and optimization of individual vehicle models. They require information on many vehicle parameters such as engine size, transmission type, transmission shift logic, gearing, and vehicle weight, which increases accuracy but also the time and effort in profiling the entire vehicle fleet.

For the longer-term option, special consideration was given to using the EPA Motor Vehicle Emission Simulator (MOVES) model because it is currently the basis for the emissions equations in HERS and because of its widespread use and reputation. Indeed, for the 2011 Urban Mobility Report, the Texas Transportation Institute switched to estimating wasted fuel due to congestion based on regression analysis of results from the MOVES model simulations. (In previous years' editions of that report, the estimation was based on the results of field tests conducted in the 1970s in which fuel consumption was measured for vehicles driving on urban arterials.) On the other hand, the vehicle operating cost scoping study identified a number of limitations of the MOVES modeling of fuel consumption that would need to be addressed. In particular, the model's "operating bins" that describe vehicle operating conditions—i.e., the combination of drive cycles and amount of energy demanded (Vehicle Specific Power)—were found to be too coarse for HERS requirements. A consequence of this lack of detail is that the model tends to over-predict fuel consumption at high speeds.

Another phase of this vehicle operating cost scoping study is still underway, which involves the development of recommended options for enhancing the HERS treatment of vehicle operating costs other than fuel. A key reference in the related research literature under review is the National Cooperative Highway Research Program (NCHRP) Report 720, Estimating the Effects of Pavement Condition on Vehicle Operating Costs. Because this report considers impacts on fuel consumption among the other impacts of pavement condition, the focus partly overlaps with that of the completed first phase of the current FHWA study.

For fuel consumption and tire costs, NCHRP Report 720 presents research that calibrated the World Bank HDM 4 model to U.S. conditions using data from Michigan road tests. In common with the models being considered as platforms for revamping the HERS fuel consumption equations (e.g., MOVES, VEHSIM), the models of fuel consumption and tire costs within HDM 4 are "mechanistic," meaning that they draw on the theoretical laws of physics. In contrast, "empirical" models are developed purely from field tests and generalizing their results much beyond the context in which the tests were conducted (the year, country, etc.) is not viable. Mechanistic models can be adapted to different contexts through empirical calibration that is a generally less data-intensive than re-estimating a purely empirical model. As indicated above, the TRDF study model from which the HERS vehicle operating cost equations derive is largely empirical. For vehicle repairs and maintenance, for which models have generally been empirical, the NCHRP study took an approach that combined (1) development of a hybrid mechanistic-empirical model and (2) updating the TRDF study model using recent data on the vehicle fleets of the Texas and Michigan DOTs.

For fuel consumption, the results of the NCHRP study indicate that pavement condition as measured by average roughness has a significant effect. In the illustrations provided for medium-size cars, increasing the measure of roughness (IRI) from 1 to 3 meters per kilometer (equivalent to raising it from 63 to 189 inches per mile) increases fuel consumption by 4.8 percent. (This is the estimate after the calibration of the HDM 4 model to U.S. conditions; without calibration, the estimate is 2.6 percent.) To put these IRI values into context, the threshold for good ride quality identified in Chapter 3 is an IRI value of less than 95 inches per mile, and the threshold for acceptable ride quality is an IRI value of less than or equal to 170 inches per mile. Thus, an IRI value of 63 would be considered good, while an IRI value of 189 would not meet the definition of acceptable. In 2010, approximately one-half of vehicle miles traveled (VMT) on Federal-aid

highways was on pavements with good ride quality, while 18 percent of VMT was on pavements with poor ride quality (i.e., ride quality that was less than acceptable).

Bridge Performance Issues

The National Bridge Investment Analysis System (NBIAS) model has undergone several enhancements since its first use to refine and improve its predictions of future funding needs for the Nation's bridges. A number of additional enhancements are under consideration.

Element Level Data Versus Summary Rating Data

The NBIAS model is capable of using detailed bridge element level data to conduct analysis of bridge conditions. If this level of detailed information is not available, NBIAS can generate element level data based on the types of summary ratings included in the National Bridge Inventory (NBI) by combining statistical models, engineering judgment, and heuristic rules to synthesize representative condition levels of bridge elements. The NBIAS model has been used to conduct analysis using databases compiled using one or the other of the two above methods but not using a database with both types of bridge data.

MAP-21 requires that States begin reporting element level data for all bridges on the National Highway System to NBI within two years of its enactment. (MAP-21 also requires that a study be conducted on the benefits, cost effectiveness, and feasibility of requiring element-level data collection for bridges not on the National Highway System [NHS].) This presents a challenge from an NBIAS perspective because the model cannot currently process a single database that contains element level data for some bridges and summary ratings for other bridges.

It would be possible to analyze two different databases (one with element-level data and one with summary ratings) separately and combine the results, but this would prevent direct investment tradeoffs between NHS bridges and non-NHS bridges to be considered. A better solution would be to adapt NBIAS to accept both types of data as inputs simultaneously; FHWA plans to pursue this option, and will adapt the software accordingly, if this approach appears to be viable from a programming perspective.

Linkages With HERS

Future enhancements to NBIAS may provide the capability to take advantage of the Geographic Information System information in HPMS to permit integrated applications of the model and HERS. Linking the two models could enable improved identification of functional deficiencies on bridges, for example due to curvature characteristics on adjacent sections of highway, on which the HPMS includes data.

Currently, NBIAS does not increase the number of lanes on a bridge even when traffic volumes would warrant additional lanes. The issue of requiring additional lanes for bridges has been addressed indirectly by including costs associated with structures within the average cost per lane mile assumed in the HERS model for capacity expansion. Research is planned to add the capability for NBIAS to replace bridges with wider bridges when warranted due to traffic volumes; the widening costs assumed in HERS would be simultaneously reduced. It is anticipated that adding this capability to NBIAS will allow for a more accurate assessment of the benefits and costs associated with widening projects involving structures.

There are a large number of culverts under the Nation's roadways. Culverts are typically used to convey water under a roadway, but some provide for the movement of people or animals from one side of a roadway to the other. By definition, culverts with a length of more than 20 feet meet the criteria of a bridge and data for them is entered in the NBI. They require regular maintenance and, at some point in time, replacement. The costs associated with culverts are factored into the typical per-mile costs assumed in HERS. However, adapting NBIAS to directly analyze costs associated with culverts would generate more refined estimates of their deterioration, maintenance, and replacement needs. The FHWA is planning to initiate research that would lead to the addition of this analytical capability to NBIAS.

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User Impacts

FHWA's long-term research plans for NBIAS include improving the model's ability to measure the impact of the loss of a bridge or the restriction of its load carrying capacity. One approach would be to develop a "Risk Factor" that would be merged with the other ranking factors in NBIAS to better prioritize bridges for maintenance or construction activities. Bridges in areas where the loss of service due to failure or access restriction would create a greater hardship for the traveling public would be assigned higher risk factors and could, possibly, be scheduled for work before other bridge projects.

Additional modifications being planned would determine the time cost to bridge users that results from a broader set of deficiencies, structural (e.g., deck, superstructure, and substructure) as well as functional. The time cost, formally measured by a mean time to service interruption (MTSI) will, in concept, allow for disruptions resulting from a deficiency before being remedied (e.g., heavy trucks having to divert around a load-posted bridge) as well as from the remedial bridge work. The MTSI for each bridge can be adjusted to reflect traffic (level and composition), environmental, and other factors such as detour length and crash rates. For structural deficiencies, NBIAS currently differentiates user costs only as a function of bridge size, without considering traffic volumes or other factors.

Transit Conditions, Reliability, and Safety

TERM's condition decay curves have provided an effective means of assessing current asset conditions and expected future conditions under alternative investment scenarios, but the FTA and the transit industry in general would benefit from an improved understanding of the relationship between asset conditions and key outcome measures such as service reliability, safety, and transit ridership. It is helpful to note in this context that the intended outcome of the FTA's heightened focus on a state of good repair is not to have assets in good condition per se; it is rather to ensure quality, safe, reliable, and cost-effective transit service. Research on and understanding of the relationships between condition and other outcome measures would also improve the understanding of the merits of investment scenarios considered in future editions of this report.

Transit Vehicle Crowding by Agency-Mode

Given the nature and granularity of transit operating data as currently reported to NTD, most TERM analysis on transit operating performance is limited to the agency-mode level of detail (for example, Houston metro bus is considered as a single agency-mode). Given this limitation, TERM is not capable of determining whether some or any portions of an agency-mode's existing service (e.g., specific rail lines or bus corridors) are in need of transit capacity improvements. Rather, TERM must assess expansion and performance improvement needs for the agency-mode as a whole, without consideration of the performance of individual service corridors (this is in contrast to the highway segment HPMS data used by HERS). In this regard, TERM would benefit from the availability of corridor-level operational data (e.g., level of service supplied and service consumed), if only for a sample of the Nation's transit operators, with which to better assess transit operator expansion needs at the subagency-mode level of detail).

Transportation Supply and Demand

Cost of Travel Time

The valuation of travel time savings—equivalently, the costing of travel time—figures significantly in the benefit-cost frameworks of the models used in this report. For valuing person hours of travel time, the models basically conform to DOT guidance on this subject referenced in Chapter 10. In recommending certain average values of travel time by trip purpose, the guidance acknowledges the considerable uncertainty as to which values would be most representative, particularly in the case of travel for personal (non-business)

purposes. The guidance also notes travel time reliability—being able to predict in advance how long a trip will take—to be a distinct and complex issue in the costing of travel time, but provides no specific direction regarding its measurement. This issue is closely related to the costing of delay due to highway incidents, which is a major source of unreliability of highway travel time.

The following discussion examines the state of research in relation to the potential refinement of the HERS valuation of travel time, focusing on valuation elements for which the U.S. DOT has not established official guidance. In addition to incident delay/reliability, it also considers the vexing question of how to value travel time savings for freight, for which HERS makes an allowance that some see as conservative.

Cost of Incident Delay

Crashes and other traffic incidents (including disabled vehicles) can produce delays that are very hard for travelers to predict or plan for, particularly when these incidents result in lane closures. The HERS model differentiates this source of delay from routine traffic congestion and from traffic control devices (on road sections lacking full access control). Via a preprocessor, the model incorporates growth over the 20-year analysis period in the deployment of selected types of highway operational/Intelligent Transportation Systems (ITS) enhancements, such as ramp meters, real-time traveler information systems, and incident management systems. The benefits of these enhancements are represented in HERS as reductions in incident and other travel delay and in accidents. On the other hand, HERS does not vet these enhancements with benefit-cost analysis. The need to assign a cost to incident delay time arises primarily from the model's use of benefit-cost analysis to screen potential expansions to highway capacity. In the model and reality, adding capacity to congested sections of roadway reduces the amount of incident delay per VMT. One of the reasons for this is that closure of a single lane due to an incident represents a smaller percent reduction in capacity when additional alternative lanes are available.

The practice in HERS, and in some other models, has been to value savings in incident delay at a premium above the value assigned to savings in ordinary delay. For HERS, the rationale is that the occurrence of incidents makes travel time less reliable, which increases the risk of early or late arrival and the associated inconveniences. Travelers can reduce this risk by adding buffer time to their travel plans, but this entails inconveniences of its own. The intention in HERS is to make a rough overall allowance for these inconveniences by including a premium in the cost attached to incident delay. This premium has been set at 2.0, meaning that HERS values incident delay time as twice the value for ordinary delay time. The premium for incident delay time also features in the ITS Deployment Analysis System (IDAS) model, which FHWA developed as a tool for cost-benefit analysis of ITS deployments; when incident delay was first added to the HERS model, IDAS was utilizing a premium of 3.0. Although this value was taken into account, it did not appear to have a strong empirical basis. When a value was set for HERS, it was decided that a more conservative value of 2.0 should be utilized.

The choice of the value of 2.0 for HERS was also guided by the findings of NCHRP Report 431, Valuation of Travel Time savings and Predictability in Congested Conditions for Highway User-Cost Estimation. The findings were largely based on stated preference experiments that asked travelers for their preferences among hypothetical travel alternatives. The alternatives differed in expected travel time and in either the reliability of travel time or the amount of travel time spent under congested conditions. Similar experiments were conducted with freight carrier participants, but these were based on a very small sample and yielded weaker results. In the models estimated using the stated preference data, the values of travel time and reliability vary with traveler characteristics and, depending on the model, other variables such as level of congestion and trip purpose. As the report noted, the application of these models in benefit-cost analyses of particular road projects requires data inputs that may not be readily available. As a fallback option that it considered broadly consistent with its findings, the NCHRP study proposed that benefit-cost analyses value travel time under severe congestion at 2.5 times the rate for other travel time.

These underpinnings of the valuation of incident delay in HERS leave considerable room for improvement. The rule of thumb from the NCHRP study relates to travel under severely congested conditions rather than to incident delay as such. Its cost premium is meant to allow for both the discomfort of travel under these conditions and the associated loss of reliability, whereas the HERS cost premium for incident delay is meant only to allow for the loss of reliability. Although incident delay results in congestion, HERS does not factor into its valuations of travel time the discomfort cost of traveling under highly congested conditions. To do so only for the congestion associated with incident delay would make the model internally inconsistent. To do so for severe congestion delay in general, including that resulting from recurrent congestion (traffic values being high relative to normal capacity) and from other sources, could be an option for future enhancement of HERS. However, available evidence is insufficient to reliably implement this refinement at present, and current U.S. DOT guidance does not provide latitude to differentiate values of travel time by level of congestion.

It must also be borne in mind that the data for the NCHRP study was collected on a particular corridor (SR 91) in Southern California in the 1990s. Additional research into the valuation of travel time and reliability has been conducted since, and some recent evidence indicates that the effect of congestion on the value of travel time may differ significantly between regions.

SHRP2 Research on Value of Travel Time and Reliability

Much of the recent U.S. research on this topic has been funded under the Transportation Research Board Strategic Highway Research Program 2 (SHRP2). One of the program's four primary research areas focuses on travel time reliability—specifically, on "developing basic analytical techniques, design procedures, and institutional approaches to address the events—such as crashes, work zones, special events, and inclement weather—that result in the unpredictable congestion that makes travel times unreliable." Recently completed Project C04, Improving Our Understanding of How Highway Congestion and Pricing Affect Travel Demand, produced a number of findings relevant to an evaluation of possible future directions for valuing travel time and reliability in HERS.

The SHRP2 study relied primarily on three types of data sources on travel patterns in the New York and Seattle metropolitan regions:

- **Household travel surveys.** For each region, the study conducted revealed preference modeling using data from household surveys that ask respondents to maintain a diary of travel undertaken by household members for one or two days. These data do not include information on non-chosen travel alternatives that were available to the survey respondents, nor on the travel times and costs related to the chosen and non-chosen alternatives. The study therefore inferred and imputed this information using representations of the highway and transit networks.
- **Stated preference survey** (Seattle region). Because this approach presents survey respondents with hypothetical choices in which the travel alternatives and their characteristics are specified, it obviates the need for imputing and inferring such information. Another advantage over revealed preference analysis is the quasi-experimental design. In revealed preference analysis, the modeled determinants of travel choices may be highly correlated, which hinders estimation of their separate influences. For example, tolled express lanes offer both lower average travel time and increased reliability; the influences of these factors on traveler choices between these and general purpose lanes may be hard to empirically disentangle. These advantages must be weighed against the drawbacks of the stated preference approach. Respondents may not interpret the hypothetical alternatives as intended, may have trouble relating to them, and may make choices in the real-world quite different from those made in the research experiment.
- **Experimental data.** The study also made extensive use of data from the Traffic Choices Study, which recruited Seattle region households for a unique experiment. Participants were given a real monetary budget, but then money was deducted from the account every time they used certain roads at certain

times of day and week. Respondents were given a pricing schedule and map, as well as an in-vehicle meter that showed the price whenever they were being charged. (More information can be found at http://www.psrc.org/transportation/traffic.) The resulting data set combines, to a large degree, the best of the other types of data sets: experimental design (in common with stated preference data) and observations on actual travel choices (in common with the household travel surveys).

Several of the study's findings are of particular interest from a HERS model development perspective. First, travelers place a significant value on travel time reliability as measured by the standard deviation of travel time, which the study found to be the measure that performed best in its models. The reliability ratio—the value of reducing the standard deviation of travel time by one minute divided by the value of reducing the average travel time by one minute—was estimated in the range 0.7 to 1.5.

Second, in contrast with NCHRP Report 431, the study did not yield consistent evidence of a congestion stress factor in values of travel time. This factor was evident in the modeling results obtained for the New York region, particularly for mode choice, but not in the results for the Seattle region. The report speculates that this difference stems from the overall level of congestion being higher in the New York region. As in the NCHRP study, the estimated models included the share of travel time under relatively congested conditions or a measure of travel time reliability, but not both. In the models that included the share of travel time under relatively congested conditions, the estimated impact of this factor would also have reflected to some extent the effects of travel time reliability because these two factors are correlated. In light of this, even the results for the New York region do not clearly confirm a significant congestion discomfort component in the cost of travel time.

Third, the study found that savings on average commuting time are generally valued more highly for longer than for shorter trips, as the U.S. DOT guidance had found to be the case in previous research. However, the SHRP2 study found that the pattern reverses when trip lengths become unusually long (over 40 miles), resulting in an inverse U-shaped relationship. In addition, for the value of travel time reliability, the findings indicated a relative dampening effect for longer trips.

These findings are suggestive, but future research using more advanced data sets and methods could yield significantly different results. Among the needed improvement that the SHRP2 study identified is more comprehensive and accurate measurement of travel time reliability. The main challenge is conducting the measurement on a trip origin-destination basis rather than for individual highway links. The study noted that measurement on this origin-destination basis is still in its infancy and its own method to be only a "crude surrogate" for real-world travel time variation. In particular, its method cannot fully address nonrecurrent sources of congestion (like traffic incidents). There is also a need for research that can empirically distinguish the effect of congestion on the value of time (the stress factor) from the value of travel time reliability.

A current SHRP2 Project L04, Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools, should help resolve a number of the outstanding issues, including how to measure reliability. Although the study for SHRP2 Project C04 found that the standard deviation of travel time worked best in its models, other research has argued both on conceptual and model-performance grounds for alternative measures such as buffer time (the difference between the median and an upper percentile travel time, commonly the 95th percentile).

Valuation of Travel Time for Freight

In a recent critique of the benefit-cost analysis used for a range of potential transportation improvement projects in the San Francisco Bay region, the Reason Foundation faulted as unrealistically low the values assumed for truck travel time savings. These analyses, which were conducted by the region's Metropolitan Planning Commission, used the values of travel time in the HERS model. Estimation of these values in

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HERS is based on the resource cost approach described in Appendix A. The resource cost per hour of truck travel estimated for each cost component:

- Truck labor (the crew, usually just a driver)
- Vehicle capital cost (interest and time-related depreciation)
- Inventory cost of the truck cargo in transit.

Estimation of the labor cost component, based on average hourly cost and the average crew size, is relatively straightforward. In the vehicle capital cost, the estimate of time-related depreciation component may contain a fair amount of error, though it is unclear in which direction. The estimation procedure derives time-related depreciation as a residual after netting out the portion of depreciation that is mileage-related. Current and planned research to improve the HERS equations for vehicle operating cost should lead to significantly improved estimates of mileage-related depreciation and hence of time-related depreciation as well. The inventory cost of the freight in transit, calculated from the average value of the cargo and the interest rate, is likely a conservative allowance for the freight time cost. It does not include the costs of damage in transit from spoilage and could significantly understate the time cost for goods that cannot be stockpiled at the destination (e.g., custom orders).

In gauging the potential for error in the HERS values of truck travel time, one must consider the relative magnitudes of each component. Labor cost is the component that can be estimated with the most confidence and is also for the largest: for five-axle combination trucks, for example, it amounts to $23.34 per hour, or about three-fourths of the overall value of $31.44 per hour. Although the other components contain more scope for error, the errors would have to be substantial to translate into large errors overall.

So how large could the errors in the nonlabor components be? This question is somewhat difficult to answer from available evidence. For the time cost of freight, an alternative to the inventory interest cost calculation is to derive an estimate from stated preference studies that ask shippers about their preferences among hypothetical shipping alternatives. The association of Australian and New Zealand road transport and traffic authorities, AUSTROADS, incorporated such estimates into its 2010 guidance on values of truck travel time for use in benefit-cost analysis. The time cost of freight is a far larger component of these values than of those used in HERS. For five-axle tractor-trailer combinations, for example, AUSTROADS set the cost of freight per vehicle-hour at what was worth, in U.S. dollars, $16.13 for nonurban shipments and $31.79 for urban shipments, compared with $22.69 for the cost per driver-hour. (In 2010, the Australian dollar averaged $0.92 in U.S. dollars.) In comparison, for the same class of truck, HERS sets the time cost of freight at only $0.77 per hour versus a cost per driver-hour of $22.98.

Although this comparison might seem to suggest that HERS greatly understates the time cost of freight, the above-discussed limitations of stated preference analysis significantly limit the confidence that can be placed in the AUSTROADS estimates. Moreover, the authors of the stated preference analysis on which AUSTROADS drew describe their effort as a "first basis" for further research, and noted the need for larger samples for more statistical precision.

Other possible approaches to valuing truck travel time savings are stated or revealed preference analysis of truck carrier choices or application of logistic optimization models. The analysis of carrier choices usually takes the form of stated preference analysis. The sample of carriers providing the data for these analyses tends to be small relative to requirements for valid statistical inferences and may not be representative. Resulting estimates of the value of truck travel time savings can be strikingly large—for example, the NCHRP Report 431 estimated that carriers on average value an hour of transit saved between $144.22 and $192.83, and an hour lateness avoided at $371.33. However, the report itself described the findings as statistically weak. The Reason Foundation critique of the Metropolitan Planning Commission's analysis cited evidence from a recent academic study (Assessing the Value of Delay to Truckers and Carriers, Q. Miao, B.X.Wang, and T.M.

Adams, University Transportation Center for Mobility, July 2011, prepared for U.S. DOT Research and Innovative Technology Administration) that used both stated preference analysis and logistic optimization modeling to estimate values of truck time savings. The FHWA will be reviewing the results and methodology of this study more closely as part of a broader literature review. From an initial review, it does not appear that the stated preference analysis yields values much out of line with those in HERS. The optimization modeling yields higher values, but is based on illustrative data (commercial sensitivity makes actual data hard to obtain) for one particular metropolitan area (Houston).

Overall, the values of truck travel time in HERS would seem to be most reasonable that can be derived from available evidence. Given the limitations of the alternative approaches, the resource cost approach taken in HERS is preferable, particularly considering that the labor component of the value of truck travel time is likely the largest and can be estimated with reasonable confidence. The FHWA will monitor and assess new evidence that becomes available, although enhancements to the truck value of time will not necessarily rank among the highest priorities for HERS model development. Because traffic on Federal-aid highways consists preponderantly of light-duty vehicles, even allowing for trucks having a higher value of time, the results of HERS analyses may not be particularly sensitive to adjustments to the value of truck travel time.

Potential Improvements to HERS Valuation of Travel Time

In its program for HERS model development, the FHWA will carefully monitor the progress in research on travel time and reliability. Advances in computer and data collection technologies can be expected to contribute significantly to this progress. In particular, the developing global positioning system/probe vehicles and other distributed wireless technologies will facilitate collection of data on actual travel times and speeds on routes between origins and destinations. These data will allow measurement of travel reliability over entire trips, which matters far more to travelers than reliability on particular links traversed during their trips. (A particular link could have travel times that are unpredictable day-to-day, but deviations from what is normal could average out over the many links traversed in a trip, making the entire trip time relatively predictable.) For this reason, the SHRP2 study focused on trip reliability, as will most future research on the value of travel time and reliability.

The focus on trip reliability will create challenges in drawing on the results of such research to enhance the HERS model. HERS estimates travel time for the individual highway sections in the HPMS sample, and with some refinement could also estimate travel time reliability. On the other hand, since HERS is not a network model, it cannot perform such estimation for trips by origin and destination. Rough adjustments around this limitation may be possible, however, as is already done in the model's s treatment of induced demand (which makes rough allowance for route diversion).

The non-network nature of HERS is also an obstacle to differentiating values of travel time by trip distance. (For this reason, the model does not incorporate U.S. DOT guidance's recommendation to value personal travel time more highly when it is intercity rather than local.) However, additional evidence on the effect of trip distance could aid the interpretation of the model's results, particularly by highway functional class. (For example, long-distance trips likely form a particularly high share of traffic on rural Interstates.)

Future editions of the C&P report may include new or modified sensitivity tests regarding the value of travel time savings. One option would be to differentiate values of travel time by geography. The results from SHRP2 Project L04 confirm the strong effect of income on the value of travel time that many other studies have found. It is also known that incomes vary geographically and are typically higher in urban than in rural areas. HERS recognizes that highway improvement costs are higher in urban than rural areas, and to do likewise for the value of travel time would make for greater consistency. For growth in the value of travel time, modified sensitivity tests will eventually be needed to address future changes in technology. Driverless cars, for example, could reduce substantially the value of travel time savings by allowing travelers to undertake other tasks, including work, while in their vehicles.

Construction Costs

Allowing construction costs to change relative to consumer prices is another potential refinement for future C&P report modeling. In the Chapter 9 supplemental analysis where the timing of investment is driven by benefit-cost ratios, spending can ramp up dramatically toward the start of the analysis period. At the highest overall level of investment considered, an average of $86.9 billion per year over 20 years, 41.2 percent of the 20-year investment total would occur within the first funding period, 2011 through 2015. That means that annual spending during those first five years would average $143.2 billion, about 2.5 times as much as the $56.4 billion actually spent in the 2010 base year.

In reality, a spending increase of this scale and speed would likely drive up prices for highway construction work relative to consumer prices. Even when unemployment rates are high, as at present, such increases in demand for highway construction could run up against short-run constraints on the supply of skilled labor and other specialized resources. At present, the looming wave of baby boomer retirements and the demand for American engineering expertise being generated by the infrastructure boom in developing countries are among the factors that could create shortages in the supply of skilled labor for U.S. highway construction projects, if demand for such labor increases substantially. To the extent that some of the spending levels considered in this report's modeling would run up against supply-side constraints, they would lead to higher costs for highway construction projects, contrary to the modeling assumption that these costs remain constant. In this respect, the projections for highway conditions and performance at relatively high levels of spending are overly optimistic.

Even without major demand-side pressures, future rates of inflation could differ significantly between industries engaged in transportation infrastructure construction industries and the economy generally. A forecasting exercise would need to consider the input cost structure of these industries, the expected rates of input cost inflation, and the likely rate of industry productivity growth. The industry has also been characterized as relatively energy-intensive; together with the U.S. Energy Information Administration projections for sharp increases in energy prices—relative to the consumer price index, a 45 percent increase between 2010 and 2030—this could suggest future upward pressures on the industry's output inflation rate relative to general inflation.

The industry's future productivity growth relative to the rest of the economy is also an important determinant of its relative inflation rate. An example of such growth is the significant advances in recent years in the development of long-life asphalt and concrete pavements. Common practice in forecasting industry growth combines reliance on expert assessments of future technology prospects with extrapolations from estimates of past rates of productivity growth. For the construction sector, however, the measurement of productivity growth is often made challenging by the lack of adequate price indices for the sector's output. For highway construction prices, the changeover from using the FHWA Bid Price Index to using its successor, the National Highway Construction Cost Index, has created some uncertainty about the rate at which prices increased in the recent past, as was discussed in Chapter 10 of the 2010 C&P Report. Moreover, neither of these indices adequately reflects the decreases in quality-adjusted prices that result from technological advances such as the above-mentioned development of new construction techniques that make pavements longer-lived. For transit investment, matters are still worse: the transit industry does not even have a price index suitable for inflating historical costs to current or future levels. TERM's needs estimates and those of the transit industry in general would clearly benefit from the availability of a transit-specific capital cost index.

Such problems with the price indices hinder the measurement of past real growth in industry output, and hence of past productivity trends. Nevertheless, the prospects for future productivity growth in transportation infrastructure construction warrants consideration in the preparation of future C&P reports as part of an analysis of how construction prices are likely to change relative to consumer prices.

The FHWA has initiated a scoping study to investigate possible approaches for performing such analysis. Among these approaches are econometric modeling (practiced in some States) and simulation with national economic models. The Global Insight model, for example, yielded forecasts of highway construction costs that indicated percentage increases between 2010 and 2016 above most forecasts of Consumer Price Index inflation. Another model that might be used is the United States Applied General Equilibrium (USAGE) model, which FHWA will be using to estimate economic impacts of changes in overall highway investment (as discussed later in this Appendix).

Travel Demand

For highways as well as transit systems, the model-based projections presented in Part II of this report are sensitive to variations in assumptions about future travel demand. The assumptions in the current versions of the models have been described in Chapter 7 for HERS and Chapter 8 for TERM. NBIAS is less sensitive to travel demand than the other two models.

Highway VMT Forecasts

The HERS model uses as a baseline the section-level forecast of VMT in the HPMS sample. FHWA has recently initiated a study to investigate the forecasting procedures being used by the States, on which HPMS Field Manual provides only general guidance. The manual requires a forecast for each sampled section, "which may cover a period of 18 to 25 year periods from the data year of the submittal." On choice of methodology, the manual allows wide latitude ranging from projections of existing trends to forecasts from travel demand models. Based on the findings about current practice, the study underway will assess options for changing the guidance and the HERS model assumptions. The goals of recommended changes will be increases in forecasting accuracy and consistency among forecasts or between them and the HERS model assumptions.

The procedure in HERS for adjusting the baseline forecasts assumes values for two types of demand elasticities: general and route diversion. Conceptually, a general elasticity describes a relationship at a system level and measures both VMT and average cost per VMT for an entire highway network. The modeling in this report assumed the general elasticity to have a long-run value of -0.8, meaning that a 1.0-percent reduction in travel cost systemwide would generate approximately 0.8 percent of additional VMT systemwide in the long run. For short-run responses, the model assumes a general elasticity of -0.4. These values are somewhat lower than those originally assumed based on review of related research conducted over a decade ago. The values were reduced starting with the 2006 C&P Report because some of the more recent research at the time seemed to point toward lower values.

As the first phase of a study to enhance the HERS treatment of induced demand, FHWA undertook an effort to re-estimate general elasticity based on a full review of relevant evidence. The review was completed in 2012 but too late to adjust the demand in light of its findings, which pointed toward elasticities close to those originally assumed: -0.6 for the short run and -1.2 for the long run. Some of the evidence reviewed came from models in which demand for travel depended on household income as well as the cost of travel. The effect of household income was found to be positive; as noted in Chapter 10, HERS would need to be modified to reflect this effect because it currently treats growth in travel time costs related to growth in household income in the same manner as it would an increase in travel time cost resulting from increased congestion, operating through the elasticity mechanism in HERS to reduce travel demand. The second phase of the study on induced demand will consider ways to deal with this inconsistency was well as the problems in modeling induced demand within a non-network model. Appendix D of the 2010 C&P Report described in detail the current representation of induced demand in HERS.

Transit Ridership Growth Forecasts

For all but the 2010 editions of this report, TERM's estimates of the investment expansion needs for transit were founded solely on the rate of growth in transit demand (passenger miles traveled [PMT]) as projected by the Nation's Metropolitan Planning Organizations (MPOs). Observers have always expressed concern regarding this use of the MPO forecasts to generate unconstrained expansion needs estimates because these PMT growth projections are themselves based on financially constrained travel demand models (i.e., MPO PMT growth projections make assumptions regarding the level of potential future funding for transit capital improvements, including how those funds will be distributed between various modes and projects, with subsequent impacts on the rate of growth in transit ridership within each urbanized area). Hence, when used by TERM, the MPO growth forecasts effectively represent constrained PMT growth projections that are used to project unconstrained transit capital expansion needs.

As in the 2010 edition, this edition of the C&P report has addressed this issue by labeling expansion needs based on MPO projections as a "Low Growth" scenario and by also introducing a "High Growth" scenario based for each urbanized area on its historical average rate of growth in PMT, which is roughly 60 percent higher than the low, MPO-projected rates. Future editions of the C&P report might consider other approaches to projecting PMT growth for assessing future transit capital expansion needs. Additional understanding of the factors that determine demand for transit services is needed.

Productivity and Economic Development

A better understanding of how transportation investments affect the economy continues to be a priority for FHWA research. MAP-21 emphasizes the importance of transportation to improve economic efficiency. It requires the U.S. DOT to establish a national freight network and develop a national freight policy that will improve the condition and performance of the national freight network to provide the foundation for the United States to compete in the global economy, with goals to improve economic efficiency. This would require FHWA to develop performance measures that track freight movement and economic activity.

In the 2010 C&P Report, Appendix D discussed a developing shift in FHWA's approach to modeling the national economic impacts of highway investment. Earlier econometric studies of productivity gains from highway investment yielded estimates that were unstable with respect to reasonable changes in model specification or sample period. One possible explanation of this problem is that the marginal returns from additional investment have declined over the years as the highway network has expanded, to the point where they have become difficult to econometrically decipher and pin down.

An alternative approach that is now being explored is simulation with national economic models drawing on evidence from benefit-cost analyses. After analyzing the capabilities of various macroeconomic models (econometric, input-output, and computable general equilibrium), the USAGE model has been selected for further testing and development. USAGE is a 500-industry dynamic computable general equilibrium model of the U.S. economy developed at Monash University in collaboration with the U.S. International Trade Commission. It was the only model that satisfied all of the following criteria important for estimating the economic effects of transportation investments:

- The freight-carrying modes are represented as separate industries, and substitution between modes can be represented.
- The model can represent a change in the productivity of each freight mode through a change in the highway (or other modal) capital stock input it utilizes, or in the technical parameters defining the productivity of the industry. Further, changes in prices of the freight services influence demand for those services, consistent with economic theory.

- The model allows for prices and demand to adjust in response to changes in taxation policy (primarily fuel and income taxes).
- The model can account for short-term Keynesian effects of government spending under the presence of slack resources (i.e., stimulus effects).

The USAGE model will be run using the outputs of the HERS model as its inputs to estimate the economy-wide impacts of increased investment in transportation infrastructure, as well as other transportation policy scenarios. In contrast with this focus on national-level impacts, other research has been investigating the impacts of highway improvements on State, regional, or local economies—for example, the SHRP2 Projects C03 (Interactions between Transportation Capacity, Economic Systems, and Land Use merged with Integrating Economic Considerations Project Development) and the follow-on SHRP2 project C11. Although the focus of such research is not directly related to the HERS model, the results would be useful for other modeling, possibly including application of the State-level version of HERS, HERS-ST, which is maintained by FHWA.

Another research study looked at the relationship between transportation investments and the economy. Historically, the growth in VMT has mirrored the growth in the economy, suggesting a strong correlation between the two. A literature search was conducted to find the current state of knowledge on the relationship between growth in Gross Domestic Product (GDP) and VMT. Current literature on this subject is limited and the evidence is inconclusive on the direction or the nature of this relationship. Understanding how changes in VMT affect GDP is important because some MPOs look to reduce VMT as a way to reduce the externalities of vehicle use including greenhouse gas (GHG) emissions, pollution, and roadway congestion. Alternatively, policies to attain lower GHG emissions could be achieved through the use of alternative fuel or technologies to improve fuel efficiency, and congestion reduction goals could be achieved by means other than reducing total VMT. Knowing how changes in VMT affect GDP could influence transportation policy decisions about congestion and GHG emissions.

A Performance-Based Approach to Addressing Greenhouse Gas Emissions through Transportation Planning

U.S. Department of Transportation
Federal Highway Administration

Quality Assurance Statement

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Technical Report Documentation Page

1. Report No. FHWA-HEP-14-020	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle A Performance-Based Approach to Addressing Greenhouse Gas Emissions through Transportation Planning		**5. Report Date** December 2013 **6. Performing Organization Code**
7. Authors Michael Grant (ICF), Sarah Siwek (Sarah J. Siwek & Associates), Laurence O'Rourke (ICF), Eliot Rose (ICF), Jenny O'Connell (ICF)		**8. Performing Organization Report No.**
9. Performing Organization Name and Address ICF International, Inc. 9300 Lee Highway Fairfax, VA 22031 Sarah J. Siwek & Associates 4519 Admiralty Way, Suite #140 Marina Del Ray, CA 90292		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTFH61-11-D-00033
12. Sponsoring Agency Name and Address United States Department of Transportation Federal Highway Administration 1200 New Jersey Ave. SE Washington, DC 20590		**13. Type of Report and Period Covered** September 2011 – December 2013 **14. Sponsoring Agency Code** HEPN
15. Supplementary Notes John Davies, Federal Highway Administration, COTM		
16. Abstract This publication is a handbook designed to be a resource for State DOTs and MPOs engaged in performance-based planning and programming to integrate greenhouse gas performance measures into transportation decisionmaking. It discusses key approaches for integrating GHG emissions into a PBPP approach, considerations for selecting an appropriate GHG performance measure, and using GHG performance measures to support investment choices and to enhance decisionmaking.		

17. Key Words Transportation planning, greenhouse gases, emissions, performance measure, performance-based planning and programming, objectives-based, goal setting, target setting, State DOT, metropolitan planning organization	**18. Distribution Statement** No restrictions. This document is available to the public from the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 58	**22. Price** N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Acknowledgements

This Handbook was developed with the assistance of an expert panel that comprised practitioners from a range of agencies to provide input to the development of this document. Their input, received during several webinars and two in-person meetings, was invaluable in shaping the Handbook. We would like to thank the following individuals who were part of the expert panel:

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Contents

Acronyms and Abbreviations

AASHTO – American Association of State Highway Transportation Officials

AB 32 – California Assembly Bill 32

AR5 – Fifth Assessment Report

ARC – Atlanta Regional Commission

Caltrans – California Department of Transportation

CARB/ARB – California Air Resources Board

CH_4 – Methane

CO_2 – Carbon Dioxide

CO_2e – Carbon Dioxide Equivalent

DOT – Department of Transportation

DRCOG – Denver Regional Council of Governments

DVRPC – Delaware Valley Regional Planning Commission

EERPAT – Energy and Emissions Reduction Policy Analysis Tool

EMFAC – California's Emissions Factors Model

EPA – Environmental Protection Agency

GBNRTC – Greater Buffalo Niagara Regional Transportation Commission

GHG – Greenhouse Gas

GTC – Genesee Transportation Council

GWP – Global Warming Potential

HFCs – Hydrofluorocarbons

HPMS – Highway Performance Monitoring System

IPCC – Intergovernmental Panel on Climate Change

LCDC – Land Conservation Development Commission

LRTP – Long Range Transportation Plan

MAP -21 – Moving Ahead for Progress in the 21st Century

MassDOT – Massachusetts Department of Transportation

MDE – Maryland Department of Environment

MOVES – Motor Vehicle Emission Simulator Model

MPO – Metropolitan Planning Organization

MTC – Metropolitan Transportation Commission

N_2O – Nitrous Oxide

NAAQS – National Ambient Air Quality Standards

NCTCOG – North Central Texas Council of Governments

NJTPA – North Jersey Transportation Planning Authority

NYSDOT – New York State Department of Transportation

PBPP – Performance-based Planning and Programming

PSRC – Puget Sound Regional Council

RTAC – Regional Targets Advisory Committee

SACOG – Sacramento Area Council of Governments

SB 375 – California Senate Bill 375

SCS – Sustainable Communities Strategy

SHSP – Strategic Highway Safety Plan

SIT – State Inventory Tool

STIP – Statewide Transportation Improvement Program

TDM – Transportation Demand Management

TIP – Transportation Improvement Program

TPB – Transportation Planning Board

TRB – Transportation Research Board

VMT – Vehicle Miles Traveled

Forward

Why reduce greenhouse gas emissions?

Climate models predict that the global climate will shift in a number of ways over the next century in response to continued emissions of greenhouse gases (GHGs). According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), global mean surface temperature is likely to rise by 2.0°F to 8.6°F (1.1°C to 4.8°C) by 2100, based on different scenarios in which human-produced GHGs are either constrained by mid-century or continue to rise. As the ocean warms and the melting of glaciers and ice sheets accelerates, we are likely to see global average sea levels higher by 12 to 32 inches.[1] Rainfall patterns are likely to change, with some parts of the world becoming wetter and experiencing more intense and frequent extreme precipitation events, and other parts becoming hotter and drier. The frequency and duration of heat waves is also very likely to increase. Climate changes are already clearly observable over the last century based on direct measurements and remote sensing from satellites, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. During the 20th century, GHG concentrations in the atmosphere have increased, the oceans have warmed, global sea levels have risen about 7 to 8 inches, and global average temperatures have increased by about 1.4°F. The IPCC has concluded that "[w]arming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia."[2]

Most climate scientists now agree that increases in global concentrations of GHGs, largely attributable to humans, are the predominant cause of climate change.[3] Human activities, such as driving cars, producing and consuming energy, and clearing forests, are significant contributors to GHG emissions, which are emitted into the atmosphere at a faster rate than they are absorbed back into the earth's land and water masses. The principal source of GHG emissions from human activities is the combustion of fossil based fuels, including oil, coal, and natural gas.

Climate change may have potentially catastrophic effects on both the natural and human environments as it disrupts ecosystems and threatens buildings, infrastructure, and human health. Expected shifts in

[1] IPCC, Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Quin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Climate effects are described for scenarios RCP4.5, RCP 6.0, and RCP 8.5

[2] Ibid.

[3] IPCC, Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Also, supported by the IPCC Fifth Assessment Report.

climate may reduce crop yields, increase the risk of invasive species, exacerbate drought conditions, and threaten endangered species.[4]

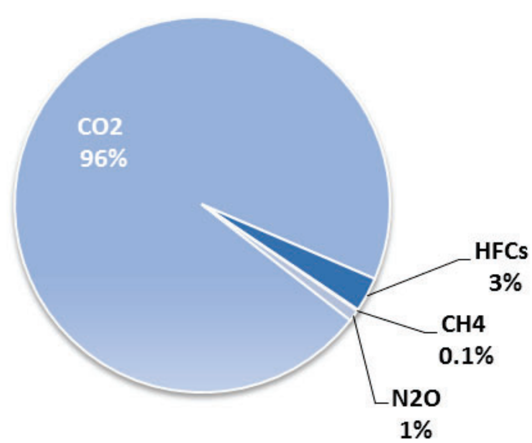
The built environment is also at risk. Human settlements in coastal and low-lying areas are particularly vulnerable to changes in sea level and to storm and precipitation events. These areas will almost certainly be at higher risk from flooding as the climate changes. Transportation infrastructure in particular will be threatened by shifts in the global climate. Changes in temperatures, precipitation, and water levels threaten to strain asphalt roadways, railroads, airports, and shipping lanes beyond the design conditions they were built to withstand.

According to the IPCC, limiting climate change will require substantial and sustained reductions of GHG emissions. Global GHG emissions must be reduced to 50 to 85 percent below year 2000 levels by 2050 to limit warming to 2.0°C to 2.4°C (3.6°F to 4.3°F).[5] Limiting global warming to approximately 2.0° C is often considered a level that will minimize many of the worst effects of climate change. An increasing number of nongovernmental organizations and U.S. States are now calling for this scale of reduction in emissions. A short term target was identified by President Obama in 2009 when he made a pledge to reduce U.S. GHG emissions by roughly 17 percent below 2005 levels by 2020 if all major economies agreed to limit their emissions as well. This target was reaffirmed in the President's Climate Action Plan in 2013.[6]

What greenhouse gases are produced by transportation?

GHGs are heat trapping gases that are released into the atmosphere from a number of sources. The four main gases that comprise transportation GHGs are carbon dioxide (CO_2), various hydrofluorocarbons (HFCs), nitrous oxide (N_2O), and methane (CH_4).

Transportation Greenhouse Gases



CO_2, CH_4, and N_2O are all emitted via the combustion of fuels, while HFCs are the result of leaks and end-of-life disposal from air conditioners used to cool people and/or freight. Carbon dioxide makes up the vast majority of transportation GHGs

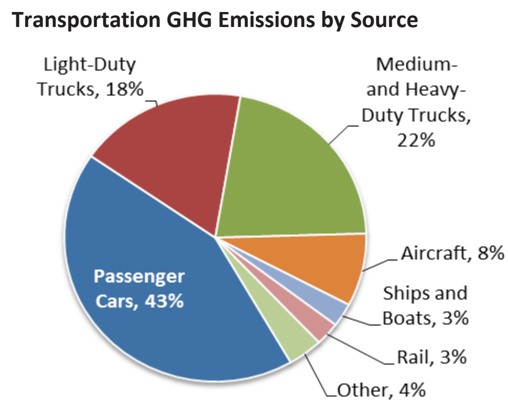
[4] U.S. EPA. 2013. Climate Change Impacts and Adapting to Climate Change. http://www.epa.gov/climatechange/impacts-adaptation/.

[5] IPCC, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007, B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[6] The President's Climate Action Plan. June 2013. http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.

in the United States, at about 96 percent, weighted by 100-year global warming potential (GWP). CO_2 is released into the atmosphere through burning fuels such as gasoline and diesel. HFCs are the second most important GHG from transportation comprising approximately three percent of GHGs measured in CO2 equivalent (CO_2E). N_2O comprises about one percent of GHGs and CH_4 about a 0.1 percent.[7]

How do transportation agencies reduce emissions?



The transportation sector directly accounts for roughly 28 percent of total GHG emissions in the U.S. It is also a significant source of indirect emissions through the extraction and refining of fuel, the manufacture of vehicles, and the maintenance of supporting infrastructure. In 2011, over 83 percent of direct transportation emissions came from on-road vehicles. Passenger cars and light-duty trucks (which include pick-up trucks and minivans) together make up the largest share of transportation GHG emissions at 61 percent (passenger cars at 43 percent and light-duty trucks at 18 percent). Medium and heavy-duty trucks, which are largely used in freight movement, made up 22 percent of transportation GHG emissions.[8] Consequently, reducing transportation GHG emissions significantly will require reductions in emissions from on-road vehicles.

Most analyses have shown that a suite of strategies is necessary to make significant reductions in GHG emissions from transportation sources. It is important that States and MPOs identify the key drivers of GHG emissions in their areas and then analyze potential GHG reduction strategies to assess potential effectiveness in their specific State or regional circumstances.

Transportation GHG reductions can be achieved by implementing strategies in five broad categories:

- Vehicle efficiency,
- Low-carbon fuels,
- Reductions in Vehicle Miles Traveled (VMT),
- Vehicle/systems operations, and
- Construction/maintenance and agency operations.

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[7] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011*, 2013.
[8] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011*, 2013.

Vehicle and fuel standards are regulated at the national level, but States also play a role. For instance, State DOTs and MPOs can influence State policies and take other actions such as education, supporting low-carbon fuel planning scenarios, and reducing fuel use by public fleets. Agencies can also support truck stop electrification, and related strategies to reduce vehicle fuel use and promote use of alternative fuels.

State Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) can contribute to reductions in motor vehicle emissions through transportation system investments, such as multi-modal transportation options that reduce dependence on vehicle travel, and operational strategies and targeted capacity improvements to reduce recurring and non-recurring congestion. State and local governments can also implement a range of strategies, including those related to land use planning, incentives to purchase more energy efficient vehicles, or other pricing mechanisms. Moreover, agencies can reduce construction/maintenance-related emissions through policies and contracting requirements that include improving equipment fuel economy, using alternative equipment technologies and fuels, and using recycled and alternative materials, among others.

The purpose of this handbook is to assist transportation agencies in their efforts to reduce GHG emissions by integrating GHG emissions into a performance-based planning and programming process.

1. Introduction

Background

The Nation's surface transportation system requires significant investment, yet most transportation agencies are operating with increasingly constrained financial resources. Within this environment, State Departments of Transportation (DOTs), metropolitan planning organizations (MPOs), transit providers, and other transportation agencies have increasingly been applying performance-based approaches to support investment decisionmaking and to prioritize investments. Performance-based planning and programming (PBPP) is the application of performance management principles to the investment decisionmaking process, using data and tools to make investment decisions based on their ability to lead to improved system performance outcomes.

Because a performance-based decisionmaking approach is focused on ensuring that transportation investment decisions are made based on their ability to address transportation system and societal goals, PBPP is a cost effective way to make decisions in an environment of limited financial resources. A performance-based approach to investment decisions improves resource allocation since information about past and expected future system performance is used to inform the selection of strategies, projects, and programs. Enabled by improvements in data collection and analysis techniques, transportation agencies can utilize information on anticipated investment impacts to develop priorities for funding. The result is increased transparency by providing clearer documentation about the reasoning for specific transportation spending choices and the impacts of transportation investments. Such transparency can yield increased public understanding, trust, and involvement.

As the prevalence of performance-based planning and programming grows, many States and regions across the country have also been recognizing the important role that transportation plays in climate change, and have begun to consider and/or implement strategies to reduce greenhouse gas (GHG) emissions. As of 2013, 32 States have developed Climate Change Action Plans, which identify policy recommendations to reduce GHGs.[9]

States and regions also have begun to integrate GHG emissions considerations in transportation planning decisions. Some State departments of transportation (DOTs), including Maryland and Vermont, have developed climate action plans focused on transportation emissions reductions. Under California's Senate Bill 375 (SB 375), the Sustainable Communities and Climate Protection Act of 2008, every MPO in the State is required to develop a sustainable communities strategy (SCS) that details its approach for meeting a regional GHG emission reduction target set by the State's Air Resources Board (CARB). As a result of the differing analytical capabilities of different agencies, California's MPOs have taken various

[9] U.S. Environmental Protection Agency, State and Local Climate and Energy Program, Climate Climate Action Plan web page, http://www.epa.gov/statelocalclimate/state/state-examples/action-plans.html, accessed July 10, 2013.

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analytical approaches to modeling transportation-related GHG emissions. New York State Department of Transportation has developed guidance for each of the MPOs in the State to analyze GHG emissions as part of the development of their long range transportation plans (LRTPs) and Transportation Improvement Programs (TIPs). MPOs have also begun to develop goals related to climate change and sustainability to help guide their plan development, and a number of MPOs have developed forecasts of transportation GHG emissions and analyses of potential GHG reduction strategies.[10]

Moving Ahead for Progress in the 21st Century (MAP-21), signed into law in 2012, places increased emphasis on performance management within the Federal-aid highway program. The MAP-21 establishes a set of national goals, including environmental sustainability.[11] States and MPOs must provide for the establishment and use of a performance-based approach to transportation decisionmaking to support the national goals.[12]

Handbook Purpose

This handbook is intended to serve as a resource for State DOTs and MPOs interested in addressing GHG emissions through performance-based planning and programming (PBPP). It describes considerations for selecting relevant GHG performance measures, techniques for evaluating performance, and approaches for using performance information to support investment choices and enhance decision-making.

This document builds on a wealth of related resources addressing PBPP, as well as resources focused on integrating GHG emissions considerations and related analysis in decisionmaking. (See Section 9 for references to many useful supporting documents.)

Handbook Organization

This Handbook is organized in the following sections, designed to answer key questions that transportation planners and other stakeholders may have about addressing GHG emissions within a PBPP approach:

- Section 2: What is Performance-based Planning and Programming?
- Section 3: Key Considerations for Addressing GHGs in a Performance-based Approach
- Section 4: Establishing Goals and Objectives
- Section 5: Selecting Greenhouse Gas Performance Measures
- Section 6: Analyzing Trends and Setting Targets

[10] For instance, the Atlanta Regional Commission (ARC), Atlanta's MPO, performed a forecast of regional GHG emissions through the year 2030 under several policy and land use scenarios (Atlanta Regional Commission's PLAN 2040 and associated documents. Available at: http://www.atlantaregional.com/plan2040/documents--tools).

[11] 23 U.S.C. 150(b).

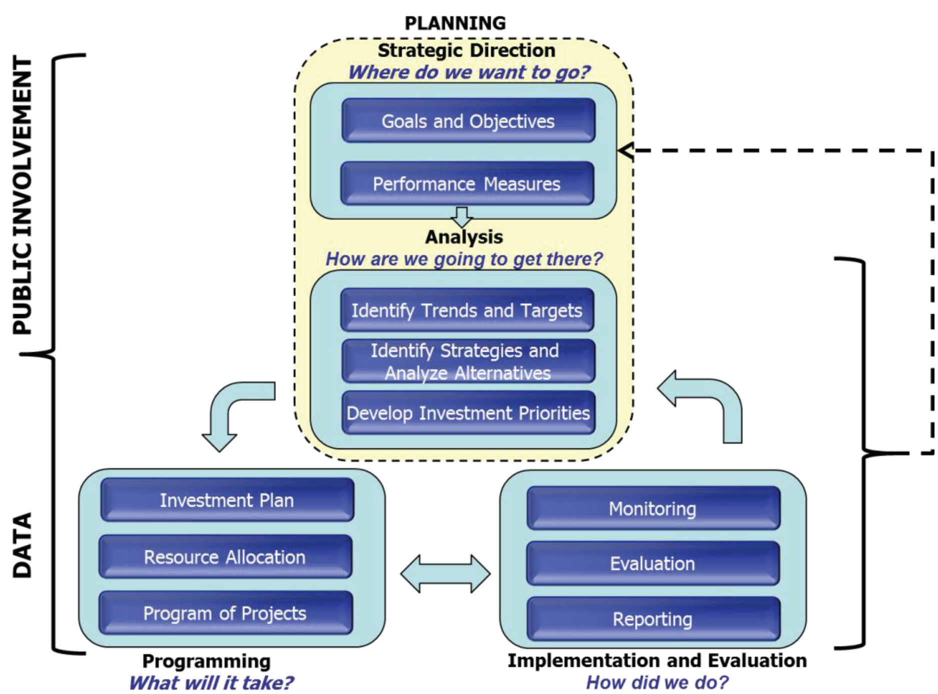
[12] 23 U.S.C. 134(h)(2) and 135(d)(2).

- Section 7: Identifying Strategies, Analyzing Alternatives, and Developing Investment Priorities
- Section 8: Monitoring, Evaluating, and Reporting on Performance
- Section 9: Relevant Resources

2. What is Performance-based Planning and Programming?

The emphasis on performance measurement and accountability is increasing not only in the transportation sector, but across all levels of government. In transportation, Performance-based Planning and Programming (PBPP) refers to the application of performance management principles within agencies' planning and programming processes to achieve desired performance goals and outcomes for the multimodal transportation system.[13] Linking planning and programming within a performance-based approach supports the selection, funding, and implementation of programs and projects to achieve desired outcomes. The figure below shows basic elements of a performance-based planning and programming process. It is important to note that the process is iterative, as investment decisionmaking is a continuous and cyclical process in which information from implemented projects helps to inform new cycles of investment decisions.

Performance-Based Planning and Programming



Source: Performance-Based Planning and Programming Guidebook (FHWA, 2013)

PBPP starts with *strategic direction* (answering the question, "what do we want to achieve?"), and includes the development of goals and objectives, and associated performance measures. Performance measures play a critical role both in 1) informing investment decisions by serving as a basis for

[13] Performance management is the practice of setting goals and objectives; it is an on-going process of selecting measures, setting targets, and using measures in decisionmaking to achieve desired performance outcomes; and reporting results. See http://www.fhwa.dot.gov/tpm/about/tpm.cfm for more information.

comparing alternative investment strategies and policies and 2) tracking progress over time toward intended outcomes.

Planning analysis ("How are we going to get there?") relies upon data and analysis tools, along with public involvement and policy considerations, to develop investment priorities. Agencies identify trends, and directional outcomes or targets (specific levels of performance desired to be achieved within a certain timeframe) for each measure to provide a basis for comparing alternative sets of strategies. Scenario analysis may be used to compare alternative packages of strategies, to consider alternative funding levels, or to explore what level of funding would be required to achieve a certain level of performance. The result is a set of investment priorities that can be identified in the Long Range Transportation Plan (LRTP) and associated planning documents.

Programming ("What will it take?") involves the selection of specific investments to include in an agency capital plan and/or in a metropolitan or statewide Transportation Improvement Program (TIP or STIP) to support attainment of intended trends or targets. An agency may develop a mid-range (e.g., 10 year) investment plan, and develop project prioritization or selection criteria to select a program of projects.

Implementation and evaluation ("How did we do?") includes monitoring system performance (gathering information on actual conditions), evaluation (conducting analysis to understand to the effectiveness of implemented strategies), and reporting (communicating information about system performance and the effectiveness of plans and programs).

PBPP involves a range of activities and products undertaken by a transportation agency, working together with other agencies, stakeholders, and the public, as part of a 3C (continuing, cooperative, and comprehensive) process. These activities include development of LRTPs, TIPs, and STIPs; other Federally-required plans and processes (such as Strategic Highway Safety Plans, Congestion Management Processes, and Asset Management Plans); and other efforts such as corridor, investment, or modal plans that support investment decisionmaking.

FHWA, the American Association of State Highway and Transportation Officials (AASHTO) and the Transportation Research Board (TRB) have developed a number of resources on performance-based planning and programming in recent years, including Guidebooks, White Papers, and Findings from Peer Exchanges and other research activities. Many of these can be found at: http://www.fhwa.dot.gov/planning/performance_based_planning/resources/.

While there is a significant amount of information available to practitioners on performance-based planning and programming in general, little has been written to help transportation agencies consider GHG reduction as part of this process. This guidebook can help to meet the needs of communities and practitioners interested in addressing GHGs through transportation planning. Within this approach, transportation agencies will typically take the following steps, discussed through sections of this document:

- Identify how GHGs relate to key goals and objectives (Section 4).
- Identify and select a GHG performance measure or measures (Section 5) – This is a key issue, since the selection of a performance measure(s) will form a foundation for understanding baseline conditions and anticipated trends, establishing targets, analyzing alternative investment strategies, and ultimately for providing information that supports planning and project selection decisions.
- Analyze trends and set targets (Section 6) – Conduct planning analysis, including development of a baseline inventory and forecast of GHG emissions, and identify desired outcomes for GHG levels to be achieved.
- Analyze alternative investment and policy strategies, and make decisions about investment priorities that are incorporated into the LRTP. Develop an investment plan and program of projects for inclusion in the TIP or STIP, using GHG reduction as one factor in helping to prioritize projects for selection (Section 7).
- Monitor, evaluate, and report on progress toward achieving desired outcomes (Section 8).

Integrating GHGs into PBPP does not mean that all projects will reduce GHG emissions, or that the selected set of investments and policies will be the alternative that minimizes GHG emissions. It should, however, provide an informed basis for investment decisionmaking to support environmental sustainability and allow a more rigorous consideration of both tradeoffs and co-benefits of GHG emissions reduction in relation to other goals.

3. Key Considerations for Addressing GHGs in a Performance-based Approach

Key Attributes of GHG Emissions

Climate change is an issue of growing concern, and methods to assess and address the issue are evolving rapidly. Many States and MPOs have set aggressive GHG reduction targets and transportation agencies have a role to play in meeting this challenge. Increased interest from policy makers and planners at all levels of government demonstrates that there is growing awareness of the challenges of climate change. This section discusses four key attributes of GHG emissions that should be considered by agencies as they seek to address this issue in transportation planning and programming.

GHG Emissions are Global, Not Local

The severity of climate change is determined by the total concentration of GHG emissions in the earth's atmosphere. Though scientists have broadly projected the level of global change that we can expect to see with different levels of emissions, it is less certain how this change will affect different areas of the globe. Moreover, the impacts experienced locally will not necessarily be in proportion with the amount of emissions that a city, metro area, or State produces. This means that the scope of emissions (in terms of the geographic area where emissions are generated, the source of the emissions) is a key concern to address when selecting GHG performance measures. It also means that GHG reduction efforts are often driven by the aim of increasing the collective impact of overlapping efforts at the local, State, national levels to reduce global emissions.

GHG Emissions are Cumulative

Unlike criteria pollutants, which stay in the atmosphere for a relatively limited time, many GHG emissions remain in the atmosphere for decades and even centuries. Even if human-produced GHG emissions were to dramatically decline, some climate change would occur over the coming years due to the increased concentration of emissions that is already in the atmosphere. This means that transportation agencies' efforts to address GHG emissions often take place in the context of larger-scale and longer-term efforts to address climate change. It also means that the time horizon of a transportation plan will have a substantial effect on how different GHG reduction strategies perform under different measures. As we discuss below, transportation planning decisions typically have a much greater effect on GHG emissions over the long term than over the short term. Though the cumulative impact of emissions can be challenging to analyze and address in the context of performance measurement, it is important to consider when thinking about actions to achieve emissions reductions. It should be noted that while it is critical for agencies to plan for GHG reductions on a long time-scale, this should occur in conjunction with efforts to meet short term reduction targets as well which can

make a down payment on GHG reductions. This can make the larger long term reductions required more manageable. Smaller reductions that are taken early will have cumulative impacts over time.

Exogenous Factors Significantly Impact Transportation-related GHG Emissions

In developing GHG reduction targets and in tracking progress, it is important to recognize the important role of exogenous factors – those not under the direct control of State and local agencies – including Federal policies in affecting transportation GHG emissions. Some key factors that affect GHG emissions include:

- *Population and economic growth* – Population and economic growth are key drivers of GHG emissions from on-road sources, and depending upon the performance measures used, their effects may outweigh those of transportation investments and policies. For instance, short-run economic conditions, such as a recession, may reduce commuting activity, and therefore drive down GHG emissions.
- *Fuel prices* – Fuel prices are largely driven by global market forces. They are highly variable in the short-term and highly uncertain in the long-term; yet they have important implications for GHG emissions. Low fuel prices may tend to encourage increased driving and use of less fuel efficient vehicles, and therefore increased GHG emissions, while high fuel prices may encourage the opposite.
- *Clean vehicle and fuels policies and technologies* – Vehicle technology improvements, driven by increasingly stringent motor vehicle emissions standards, have been the dominant source of reductions in vehicle emissions since the 1970s. Moving forward, Federal fuel economy standards will have a large effect on GHG emissions, as will market factors that affect the cost and availability of more efficient vehicles. In comparison with these policies and factors, States and regions generally have limited ability to require or incentivize consumers to use more efficient vehicles. It should be noted that California is different than other States in the legal authority it has to regulate vehicle technology and air emissions. To the extent that California adopts more stringent rules for vehicle technologies, other States may follow its lead by adopting its standards.

Consequently, while transportation investments and strategies play an important role in addressing GHG emissions, other factors may have a larger absolute impact on emissions, particularly in the short-term. For example, in California, the Air Resources Board estimates that regional transportation and land use policies to meet GHG reduction targets will be responsible for about one-sixth of the GHG reductions associated with standards for light-duty vehicle efficiency and low carbon fuels through 2020.[14] However, the Board also emphasizes that transportation and land use planning will play a more central

[14] California Air Resources Board, Greenhouse Gas Reductions from Ongoing, Adopted and Foreseeable Scoping Plan Measures, Available at: http://www.arb.ca.gov/cc/inventory/data/tables/reductions_from_scoping_plan_measures_2010-10-28.pdf.

role in reducing GHG emissions between 2020 and 2050 due to the long-term benefits of these strategies.[15] A study by the National Research Council on the effects of compact development also noted that the benefits of compact development increase over time, illustrating on the one hand the longevity of the built environment and, on the other, the cumulative effect of land use changes.[16,]

Many other transportation outcomes that are commonly measured in plans and programming documents are affected by exogenous factors. For instance, safety (traffic fatalities and injuries) is affected not only by roadway design and operations, but also by driver behavior and vehicle technologies. Similarly, traffic congestion is affected not only by investments in the transportation system but also by land use, fuel prices, and economic activities.

As with these examples, a transportation agency may focus on GHG emissions as a key performance measure in its planning and programming -- even emissions that are beyond its direct control – because GHG emissions are directly related to an outcome with significant impacts on society, climate change. Moreover, the transportation planning process offers a forum to bring together the public, key partners, and stakeholders in developing coordinated solutions.

GHG Emissions are Not Directly Measured

Another challenge associated with using GHG emissions as a performance measure is that GHG emissions cannot be monitored in a literal sense, the way it is possible to monitor some other outcomes such as the number of fatal crashes or metrics related to pavement and bridge conditions. GHG emissions have to be modeled or calculated using emissions factors. This approach is not unique to GHGs, since estimation and modeling are typically conducted for some metrics, such as traffic congestion measures (e.g., hours of delay experience by travelers) and measures of accessibility to transit (e.g., share of households within ¼ mile of transit). However, it is important to recognize that the available tools and assumptions that transportation agencies make when estimating GHG emissions have important implications for the results.

Fuel consumption can serve as a proxy for tailpipe GHG emissions, since fuel sales are tracked at the State level, and CO_2 is emitted in direct proportion to fuel consumption, with differences in emissions rates based on different types of fuel (e.g., motor gasoline, diesel, compressed natural gas). In fact, State-level on-road GHG emissions have often been calculated based on fuel sales in multi-sector GHG

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[15] California Air Resources Board, Climate Change Proposed Scoping Plan, Appendix C: Sector Overviews and Emission Reduction Strategies, page C-80, available at: http://www.arb.ca.gov/cc/scopingplan/document/appendix1.pdf

[16] National Research Council, *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy use, and CO_2 Emissions*. Washington, D.C.: Transportation Research Board Special Report 298, 2009. Available at http://cta.ornl.gov/cta/Publications/Reports/Reducing_GHG_from_transportation%5b1%5d.pdf. This study estimated CO_2 reductions of 1.3 to 11.0 percent compared to a baseline in 2050 due to more compact development. The broad range is based on different assumptions associated with the share of new and replacement development that is compact and the reductions in VMT in compact development areas.

inventories, since emissions of carbon dioxide (CO_2), the primary GHG, are directly related to fuel consumption, and because fuel sales data are typically readily available. However, fuel sales may not correspond exactly with travel within a particular State, especially in instances where drivers commonly travel between States (e.g., New York, New Jersey, Connecticut). These boundary issues are particularly important when examining emissions in smaller geographies, such as metropolitan areas.[17] In addition, non-road use of motor fuels means that there may be some discrepancies between fuel sold and fuel used by motor vehicles. In these cases, GHG emissions can be calculated by collecting data on vehicle miles traveled (VMT) and operating conditions and then using an emissions model, such as EPA's Motor Vehicle Emission Simulator Model (MOVES) – or California's Emissions Factors (EMFAC) model – to estimate emissions.

As a result, transportation agencies' GHG analysis will likely be shaped by the tools and data that are available, the extent to which these tools and data capture different strategies that agencies may undertake to reduce emissions, and the need for consistency with the analytical methods used in evaluating GHG emissions under overlapping climate policies. Some States and MPOs have invested in creating new tools or enhancing models to expand the analytical capabilities available to analyze policies. For instance, Oregon DOT developed the GreenSTEP model to analyze a broad range of GHG reduction strategies that could not be addressed in traditional travel models.

Policy Implications

The four factors described above demonstrate that there is no single measure that "best" addresses GHG emissions within a PBPP approach, nor is there a single correct way to calculate a given measure. Instead, several different factors can collectively shape transportation agencies' choices regarding GHG performance measures and how GHG emissions are integrated into decisionmaking, including:

- The GHG reduction strategies that are under consideration by transportation agencies;
- The geography and travel characteristics of the area under consideration (e.g., city, metropolitan area, or State);
- Consistency with other local, State, and national climate policies;
- The extent to which agencies collaborate with stakeholders to identify additional opportunities to reduce GHG emissions;
- The effect of Federal policies and other exogenous factors on GHG emissions;
- The time horizon of the planning process; and
- Available tools and data.

[17] Road based VMT in small geography analyses can also have inherent errors if the GHG is related to the population or economy (per capita and per GDP metrics) and there are significant volumes of external trips or pass through traffic.

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It is important that transportation agencies understand how these factors affect their options when selecting a GHG performance measure(s), and understand the limitations associated with various approaches. In the following sections of this guidebook, we describe different choices that transportation agencies face when selecting GHG performance measures, as well as how the factors listed above can shape agencies' options.

4. Establishing Goals and Objectives

Developing goals and objectives is a fundamental part of any successful planning effort, and this is especially true for performance-based planning and programming. Goals and objectives provide strategic direction for investment and policy decisions, and consequently play a critical role in guiding the selection of performance measures and investment priorities. Regional, State, and national goals associated with sustainability, climate change, and related community outcomes can be a primary motivation for including GHGs within a performance-based approach to transportation planning and programming. For a more detailed discussion of establishing goals and objectives in a performance-based planning and programming process, see the FHWA/FTA *Performance Based Planning and Programming Guidebook*.[18]

State and Regional Climate Change Mitigation Goals and Policies

Scientific evidence makes clear that the buildup of greenhouse gases in the atmosphere is causing the Earth's climate to change in ways that affect our weather, oceans, snow, ice, and ecosystems. Human activities contribute to climate change through the release of heat-trapping GHGs. Climate change has substantial impacts on our transportation systems and on society as a whole. For example, warmer temperatures increase the frequency, intensity, and duration of heat waves, which can pose health risks, particularly for young children and the elderly. Rising sea levels threaten coastal communities and ecosystems. An increase in the frequency and intensity of extreme weather events, such as heat waves, droughts, and floods, can harm transportation systems and cause costly

California's Sustainable Communities and Climate Protection Act of 2008

In 2006, California's legislature passed, and the Governor signed, The Global Warming Solutions Act, Assembly Bill 32 ("AB 32"), which called on the State's Air Resources Board (ARB or CARB) to prepare and approve a plan for achieving ambitious and cost-effective GHG emissions reductions, establish an emission limit for 2020, adopt a regulation requiring the mandatory reporting of GHG emissions, identify "early action" measures that could be taken to reduce emissions, and establish a cap-and-trade program.

In 2008, the Legislature passed, and the Governor signed, the Sustainable Communities and Climate Protection Act, more commonly known as "SB 375," which called on the ARB to develop emission reduction targets for cars and light trucks. The law also requires California's MPOs to prepare Sustainable Communities Strategies (SCSs) that demonstrate how each region will meet these emission reduction targets. SCS's are land use and transportation plans that are expected to address regional housing needs as well as more traditional GHG reduction approaches. The SCSs under SB 375 must also meet all the Federal requirements for a long range transportation plan. The SCS components were added to existing Federal and State requirements. The bill aims to foster the implementation of "bottom-up" solutions for addressing GHG emissions.

[18] While the terms goals and objectives are often used interchangeably, the PBPP guidebook defines a goal as a broad statement that described a desired end state, and an objective as a specific, measurable statement that supports achievement of a goal. An objective may address a focus area under a broad goal (e.g., an objective could address GHG reduction under a broad goal of sustainability), with the specific measure defined outside of the objective statement, or the objective could be defined specifically to include a measure and target (discussed further in the next two sections). See http://www.fhwa.dot.gov/planning/performance_based_planning/pbpp_guidebook/index.cfm.

disruptions to society.[19] According to the IPCC, global GHG emissions must be reduced to 50 to 85 percent below year 2000 levels by 2050 to limit these adverse effects of global warming.[20]

As noted earlier, thirty-two States and many regions have already developed climate action plans, and through those have identified transportation-related GHG emissions reduction as a desired outcome. Moreover, several States have passed laws or have had Executive Orders that call for GHG reduction. Although climate change action plans typically have not been integrated with transportation plans and programs, State and regional goals for GHG reduction may lead to a transportation planning goal or objective that addresses climate change. While in some cases State laws may influence the adoption and implementation of GHG goals and objectives, input from the community may also provide grassroots support for their adoption. For instance, the Delaware Valley Regional Planning Commission (PA-NJ) has set a specific target for reducing greenhouse gas emissions by 50% by 2035.[21]

As an example within the transportation planning process, the Mid-America Regional Council, the MPO for the Kansas City metropolitan area, adopted its LRTP, called *Transportation Outlook 2040*, in June 2010. An extensive public outreach process was utilized in the development of a regional vision statement and nine goals to serve as a foundation for the plan's content, identification of performance measures, and project evaluation and prioritization. The selected goals include several that have been used in the past – system performance, system condition, safety and security, accessibility, and economic vitality – as well as new goal areas, including one focused on climate change/energy use. The selected climate change/energy use goal is to: "Decrease the use of fossil fuels through reduced travel demand, technology advancements and a transition to renewable energy sources."[22]

Supporting Related Community Outcomes

Protecting and enhancing the natural environment is an end in and of itself, but it can also be a means to achieving other broad goals such as supporting sustainable land use patterns, encouraging walking and biking, increasing household incomes by reducing energy costs, and boosting employment through the implementation of investments in energy efficiency. A number of MPOs discuss climate change as an issue in their long range transportation plans, addressing various reasons to care about climate change.[23] These include regional concerns about the consequences of climate change, such as increases in severe weather, sea level rise, air pollution, and public health impacts.

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[19] For more information, see: U.S. Environmental Protection Agency, "Climate Change Science" web page at: http://www.epa.gov/climatechange/science/.

[20] IPCC, 2007. Contribution of Working Groups I, I and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Chapter 5, Section 5.4. Available at: http://www.ipcc.ch/publications_and_data/ar4/syr/en/mains5-4.html.

[21] Delaware Valley Regional Planning Commission, *Connections – The Regional Plan for a Sustainable Future. Public Comment Document*, 2009.

[22] Mid-America Regional Council, *Transportation Outlook 2040,* available at: http://www.marc.org/transportation/lrtp.htm.

[23] FHWA, "Climate Change – Model Language in Transportation Plans." Prepared by ICF International, 2010.

For instance, the Baltimore Metropolitan Council notes in its LRTP, called *Plan It 2035*, which was adopted in November 2011, that GHG emissions and climate change are an environmental concern for multiple reasons: "[I]ncreased runoff and rainfall events from climate change could affect the [Chesapeake] Bay through increased erosion and sediment loads. Higher peak stormwater flows also would mean greater amounts of nutrients transported downstream, degrading water quality. Additionally, climate change will likely cause a decline in biodiversity of plants and animals in the forests of Maryland. Increasing summer temperature will likely cause higher ozone levels and more frequent exceedances of the Federal ozone air quality standard. Sea level rise will also require costly mitigation measures to protect the region's transportation infrastructure from higher water and damage caused by storm surges."[24]

A number of State DOTs and MPOs also emphasize sustainability, and policies that support GHG reduction, such as managing travel demand, ensuring multimodal options, and optimizing system performance before adding new highway capacity. For instance, the Delaware LRTP, *Moving the First State Forward,* which was adopted in 2010, focuses on developing "smart transportation systems consistent with the State's smart growth strategies." These strategies seek to guide growth to areas that are most prepared to accept it in terms of infrastructure and thoughtful planning; preserve farmland and open space; promote infill and redevelopment; facilitate attractive, affordable housing; and protect quality of life while slowing sprawl. Consequently, the Plan includes goals related to economic vitality, safety, accessibility and mobility, multi-modal transportation, efficiency and effectiveness, and environmental stewardship, including integrated land use and transportation and "responsible energy consumption".[25]

The Grand Valley Metropolitan Council, MPO for the Grand Rapids, Michigan, metropolitan area, includes within its 2035 LRTP, adopted in March 2011, a vision to "Establish a sustainable multimodal transportation system for the mobility and accessibility of people, goods, and services; it will provide an integrated system that is safe, environmentally sound, socially equitable, economically viable, and developed through cooperation and collaboration." The Plan includes a goal to "Strengthen the link between transportation and land use policies to encourage people and businesses and to live and work in a manner that reduces dependence on single occupancy vehicles." Under its environmental goal, the plan includes an objective to "Prioritize transportation projects which reduce the frequency and length of trips, minimize the energy resources consumed for transportation, and promote a sustainable transportation system."[26]

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[24] Baltimore Metropolitan Council, *Plan It 2035,* Chapter 2, available at: http://www.baltometro.org/plans/final-plan-it-2035.

[25] Delaware Department of Transportation, *Moving the First State Forward: Delaware Long Range Transportation Plan*, 2010, available at: http://www.deldot.gov/information/pubs_forms/delrtp/delrtp_102510.pdf.

[26] Grand Valley Metropolitan Council, *2035 Long Range Transportation Plan,* Chapter 3, available at: http://www.gvmc.org/transportation/longrangeplan.shtml.

National Environmental Sustainability Goal

Sustainability goals at the national level have been driven by both legislative action and executive initiatives. President Obama has established a target to reduce total U.S. greenhouse gas emissions by about 17 percent below 2005 levels by 2020.[27]

The MAP-21 establishes seven national goal areas; one of these is "Environmental sustainability: To enhance the performance of the transportation system while protecting and enhancing the natural environment." [Section 1203, or 23 USC 150(b)]

Although State DOTs and MPOs are not required to use a consistent national environmental sustainability performance measure, they will be expected to use a performance-based approach to decisionmaking that supports the national goals. The MAP-21 requires that the metropolitan and statewide transportation planning process "shall provide for the establishment and use of a performance-based approach to transportation decisionmaking to support the national goals" [23 USC 134(h)(2)(A) and 23 USC 135(d)(2)(A)].

The environmental sustainability goal area could include many different focus areas or objectives, including minimizing water runoff from transportation facilities, increasing habitat restoration, encouraging the use of low-emission transportation options, such as walking, bicycling, taking public transit, or using low-emission vehicles. Given the potentially severe impacts associated with climate change, States and MPOs may choose to consider GHG emissions as a measure of environmental sustainability. GHG emissions have been identified by some States as a promising measure to track agency performance in the area of environmental stewardship.[28] It addresses a key component of sustainability – "meeting the needs of the present without compromising the ability of future generations to meet their own needs."[29]

[27] The President's Climate Action Plan. June 2013. http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.

[28] See NCHRP 20-24(37), "Technical Guidance for Deploying National Level Performance Measurements." Prepared by Cambridge Systematics, 2011. See page 3-30.

[29] Common definition of sustainability, derived from the "Brundtland definition" in the World Commission on Environment and Development, *Our Common Future* (New York: Oxford University Press, 1987).

5. Selecting Greenhouse Gas Performance Measures

Transportation agencies face numerous options when selecting a GHG performance measure or measures. This section describes several of the choices that transportation agencies face when selecting a GHG performance measure(s) and discusses how local context, overlapping climate and sustainability policies, tools, modeling and data availability, and other factors can shape transportation agencies' choices. It then discusses the pros and cons of specific commonly-used GHG performance measures.

It is important to note that a GHG measure should be carefully chosen to support public policies for GHG mitigation. The selection of a measure is not merely a technical issue, but rather is closely related to the type of vision that a State or region has developed for transportation sustainability. Ultimately the performance measure selected should assist an agency or area in implementing its vision.

A number of States have policies in place that establish transportation-related GHG reduction targets, and in some cases, specify performance measures and methodologies. Though this report outlines general considerations, the consistency of the measure with State-level policies, initiatives and community priorities should be considered carefully by transportation agencies.

Key Issues in Defining a GHG Performance Measure

The options that transportation agencies face when selecting GHG performance measures can be summarized by three questions:

1. Which emissions should we measure?
2. How should we measure these emissions?
3. How should we express the results?

Answering each of these questions will require agencies to consider how the policies that they need to implement can be supported by these measures. Below we summarize the options that transportation agencies face within the categories represented by each of the above questions.

Which Emissions are Measured

The first step in selecting a GHG measure (and correspondingly conducting most GHG analyses) is to establish the scope of the analysis, including which types of GHG emissions will be measured, which sources will be covered, and whether to account for tailpipe or life-cycle emissions.

Which GHGs to Include

Carbon dioxide (CO_2) is the most prevalent GHG and accounts for roughly 95 percent of transportation GHGs based on global warming potential.[30] As such, the number of tons or pounds of CO_2 emitted is a reasonable stand-alone indicator of GHG emissions. However, transportation emits several other GHGs, such as methane (CH_4) and nitrous oxide (N_2O), so agencies can also measure **multiple GHGs**. Some gases have a stronger effect on climate change than others; the relative strength of a given GHG's effect on the climate is commonly referred to as its global warming potential (GWP). When measuring multiple GHGs, agencies typically state results in tons of carbon dioxide equivalent (tCO_2Eq. or tCO_2e), a unit that accounts for differences in GWP. This can be slightly more complex than just measuring CO_2 emissions, but many emissions models make it easy to measure multiple GHGs in tCO_2Eq.

The choice of which GHGs are included generally does not affect the responsiveness of a performance measure to different strategies to reduce transportation-sector GHG emissions, except in the context of choices between different advanced vehicle technologies that typically occur outside of the transportation planning and programming process. Consistency with other agencies' policies and accounting methods is typically the driving factor in determining which GHGs to include in a transportation analysis.

Which Transportation Sources are Included

Transportation agencies face several choices when determining which vehicles and sources should be included in an analysis of GHG emissions:

- **Light-duty vehicle GHG emissions** accounts largely for emissions from passenger vehicles, as opposed to commercial travel.
- **Total on-road GHG emissions** accounts for the emissions produced by both passenger and freight vehicles. This is a more comprehensive approach than the measure above, and will capture the benefits of strategies to improve the efficiency of freight movement. This measure is also consistent with the scope of analysis for conformity with air quality goals, and addresses heavy-duty trucks, which in particular are a significant contributor to on-road GHG emissions.
- **Total transportation GHG emissions** accounts for GHG emissions from all transportation sources, potentially including rail, transit, and ferries in addition to on-road vehicles. This is the most comprehensive approach, and will capture the benefits of some GHG reduction strategies that other measures will ignore, such as strategies to increase the efficiency of transit vehicles. However, it is also more complicated to calculate than the two measures described above, since this measure not only requires agencies to account for more diverse sources, but also potentially to develop emissions factors for transit vehicles such as railcars that are not covered by on-road mobile source emissions models.

[30] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011*, 2013.

In addition to choosing between one of the three measures described above to describe GHG emissions related to usage of the transportation network, transportation agencies may choose to account for **construction and maintenance GHG emissions**. Though the amount of GHG emissions due to construction and maintenance of the transportation system is generally much smaller than the amount of emissions due to use of the system, transportation agencies have the potential to directly influence these emissions through procurement policies and contracting requirements. On-road emissions models do not typically account for construction and maintenance GHG emissions, but tools are available and are being developed to help agencies account for these emissions.

Greater Buffalo Niagara Regional Transportation Council (GBNRTC) Energy and GHG Analysis

Based on guidance from New York State DOT (NYSDOT), MPOs in New York State have been analyzing construction and maintenance related emissions associated with their LRTPs and TIPs. In 2007, GBNRTC completed an energy and GHG analysis of its 2030 Long Range Transportation Plan. In addition to estimating GHG emissions from vehicles, GBNRTC also estimated the "indirect" GHG emissions associated with construction of transportation infrastructure. GBNRTC's analysis included GHG emissions from construction equipment, transportation of materials, and production and extraction of materials. GBNRTC used procedures specified by NYSDOT to estimate the energy used by construction on a per lane-mile or per track-mile basis, and then converted this energy consumption to GHG emissions.

Source: Greater Buffalo Niagara Regional Transportation Council (GBNRTC), Energy and Greenhouse Gas Analysis For the Greater Buffalo Niagara Regional Transportation Council (GBNRTC) 2008-2012 TIP and 2030 Long Range Transportation Plan, July 2007, Available at: http://www.gbnrtc.org/index.php/resources/publications/reports/

Two key factors commonly play a role in transportation agencies' choice of which sources to include in GHG performance measures:

- **Agency interest in developing policies related to GHG emissions from different sources**. While including more sources is more comprehensive, it often requires more effort. Transportation agencies may choose to invest this effort only if it will offer additional insight on the relative effectiveness of different GHG reduction strategies; otherwise they typically use simpler measures in order to avoid analyzing emissions that are outside of their control. For example, passenger travel is more closely tied to regional or State transportation planning decisions (e.g., land use coordination, transit service, demand management, etc.) than freight travel, which often is primarily determined by broader economic factors and involves more interstate and interregional travel, so some transportation agencies choose to limit analysis to light-duty GHG emissions. However, if a transportation plan contains strategies to reduce freight emissions through corridor management or other measures, more comprehensive measures will be necessary to capture the resulting GHG reductions.
- **Consistency with regional emissions analysis.** Regional emissions analysis to meet Clean Air Act requirements in non-attainment and maintenance areas must consider both heavy- and light-duty vehicles. For areas that violate the National Ambient Air Quality Standards (NAAQS), this makes it easier for MPOs to account for GHG emissions from all on-road vehicles if they are analyzing GHG emissions alongside other criteria pollutants.

Addressing Life-Cycle Emissions

Transportation agencies typically focus on **tailpipe GHG emissions**, which are the emissions that are produced by vehicles as they combust fuel, because the analysis of tailpipe emissions is simpler to conduct and because it mirrors the approach that agencies typically use to assess criteria pollutant emissions. However, since GHGs are global pollutants that have the same impact on the climate regardless of where they come from, it can also be beneficial to estimate **life-cycle emissions**, which account for emissions associated with the production, transport, and disposal of transportation fuels, and potentially also emissions generated by vehicle production, maintenance and disposal. A life-cycle analysis will better account for strategies that involve shifting fuels, such as encouraging adoption of hybrid passenger vehicles or using biodiesel in transit vehicles. However, a comprehensive life-cycle analysis can also require much more effort and a greater number of assumptions on a transportation agency's part than a tailpipe analysis. An agency can pursue a mixed approach, using tailpipe GHG emissions as a primary performance measure and estimating life-cycle GHG reduction factors for strategies or projects that primarily impact life-cycle emissions. For instance, Oregon and California have quantified the impact of implementing a low carbon fuel standard. Since this approach does not result in an "apples-to-apples" comparison, it merits extra caution when interpreting results. Nevertheless, it can be helpful to understand the full life-cycle emissions impacts of investments.

How Emissions are Measured

One of the key challenges of selecting GHG performance measures is selecting measures that reflect the impact of transportation agency investments. In particular, it can be challenging to attribute global emissions to a particular State or region, or to attribute cumulative emissions that remain in the atmosphere for decades or more to a plan with a limited time horizon.[31] As a result, it is important for agencies to consider how emissions are measured at the outset when selecting GHG performance measures in order to ensure that GHG analysis is responsive to agency goals. This section broadly outlines key methodological considerations; Section 6 discusses GHG analysis methods further.

Geographic Scope of Analysis

The fact that GHG emissions are global, not local, pollutants means that transportation agencies should consider the source of emissions when analyzing GHG performance measures. A **geographic analysis** accounts for GHG emissions due to all vehicle travel that takes place within the boundaries of a region or State. This includes internal trips that begin and end within these boundaries, interregional or interstate trips, and trips that pass through the region or State. This approach is consistent with the approach used in transportation conformity for criteria pollutants. However, a geographic analysis may undercount GHG emissions due to trips that may be influenced by a region's policies or investments (i.e., interregional or interstate trips that begin or end at a point near the edges of the region or State)

[31] Different GHGs can remain in the atmosphere for different amounts of time, ranging from a few years to over a thousand years.

or count emissions from trips that are largely beyond an agency's influence (i.e., pass-through trips). Alternately, a **trip-end analysis** accounts for GHG emissions due to vehicle trips that begin or end within the boundaries of a region or State. Typically, a trip-end approach counts all GHG emissions from internal trips and half of the emissions from interregional or interstate trips, while ignoring pass-through trips. As a result, it ties the emissions most directly to their sources.

Four factors often play a role in transportation agencies' choice between a geographic and trip-end approach to analyzing GHG emissions:

- **Consistency with regional emissions analysis requirements**: Analysis of criteria air pollutants takes a geographic approach to analyzing emissions (e.g. nonattainment or maintenance area boundaries), which reflects the fact that criteria pollutants are local, not global. This can make it easier for MPOs to use geographic analysis of GHG emissions if they are analyzing GHG emissions alongside other criteria pollutants.
- **Role of inter-regional or interstate travel.** States and regions that experience a large proportion of interregional or interstate and pass-through travel may find that a trip-end analysis focuses more on the GHG emissions over which they have the most control, while areas where most travel is internal may be better suited to a geographic analysis. The amount of non-internal travel typically depends upon a State or region's size, location, and economic activity relative to nearby population centers. A geographic analysis is typically well-suited to regions or States that cover a travelshed, a large geographic area, or do not border on other population centers. This includes many western States and regions located within sparsely-populated States. On the other hand, small States and regions that are adjacent to other metropolitan areas, such as States and regions in the densely-populated northeastern U.S., will likely find that their neighbors contribute to travel within their boundaries, and that a trip-end analysis may be more responsive to certain types of transportation policies and strategies, such as those focused on VMT reduction (e.g., land use changes).
- **Strategies being considered.** If a plan contains significant elements that affect interregional or interstate travel, such as new transit connections to adjacent regions or States or major land use changes that will attract travelers from nearby population centers, a trip-end analysis may better capture the resulting GHG emissions, particularly if the focus is on passenger travel. However, if a region or State is considering or implementing strategies that include traffic operations improvements, reductions of freight bottlenecks, and other strategies that affect inter-regional and interstate traffic, a geographic analysis may be better to capture GHG emissions impacts.
- **Consistency with neighboring jurisdictions**. A trip-based analysis may leave some GHG emissions unaccounted for; particularly GHG emissions from pass-through trips. Transportation agencies will minimize the risks of leaving emissions uncounted if they coordinate with neighboring or overlapping jurisdictions to align approaches to analyzing GHG emissions. For example, under California's SB 375, MPOs use a trip-end approach to calculating emissions, and

the State DOT will conduct an aggregate analysis of all regional plans to account for emissions from pass-through trips and other interregional travel.

Accounting for Changes in Vehicle Technology

Improvements in vehicle technology have the potential to reduce transportation-sector GHG emissions significantly. At the same time, transportation agencies' control over vehicle technology is typically limited to funding research, offering incentives to consumers to purchase more efficient vehicles, and purchasing alternative vehicles and fuels for fleets. These actions often have a marginal effect on GHG emissions compared to Federal fuel efficiency standards and market factors. The way in which transportation agencies account for technology changes will affect the extent to which performance measures are responsive to GHG reduction strategies.

Measuring total GHG emissions, including emissions from technological changes, is typically the simplest approach, and may better align with State targets that specify an absolute emissions reduction goal. However, this approach will account for GHG reductions due to fuel efficiency standards and other factors that are typically beyond transportation agencies' control. Alternately, transportation agencies can **control for the effect of changes in technology on GHG emissions**, which can help to focus planning efforts on GHG reductions that are most directly under agencies' control. This approach is more complex, and the level of effort involved in controlling for technological changes depends heavily on the extent to which Federal and State policies offer a basis for controlling for GHG emissions due to exogenous factors.

How Emissions are Expressed

In addition to determining the scope of GHG emissions that will be considered in an analysis and how these emissions will be measured, transportation agencies can also choose to express emissions in ways that control for growth or are easier to communicate.

Total or Normalized Emissions

Total GHG emissions offer an indicator of the overall impact of the transportation system, and are more closely aligned with the many State-level policies that establish GHG reduction goals in terms of overall emissions. However, transportation agencies may choose to normalize GHG emissions in order to account for the effect of population and economic growth on emissions. Two common normalized GHG performance measures are:

- **Per capita GHG emissions**: This measure accounts for the effect of population growth on GHG emissions, but it does not directly address the overall environmental impact. A decrease in per capita emissions would indicate that the average resident of a region or State is reducing his or her transportation-related GHG footprint, but total emissions will still increase if population growth outpaces the decline in per capita emissions. Per capita GHG emissions can be easier to communicate and interpret than total GHG emissions because residents are more likely to be

accustomed to seeing per capita or household-level GHG emissions figures from carbon footprint calculators and other resources.

- **GHG emissions per unit of economic output**: This measure controls for the effect of economic shifts on GHG emissions, such as declines in commute-related GHG emissions due to increased unemployment. However, as with per capita emissions, this measure does not always align with overall emissions, and poses added challenges to communicating results because definitions of economic output differ among planning agencies.

Since the transportation planning process typically includes population projections, and sometimes uses performance measures that assess economic growth or other trends, normalizing emissions often does not involve significant additional effort. Therefore, it may be feasible for transportation agencies to use total and normalized GHG performance measures side by side; for example a total measure to track overall progress toward sustainability goals and a per capita measure to control for population growth and facilitate communication.

Examples of GHG Emissions Metrics

The various combinations of options for each aspect discussed above yield a large variety of potential GHG emissions metrics. However, in practice, the metrics used by transportation agencies to date typically vary in terms of three key characteristics:

- The type of vehicles that they account for,
- Whether they normalize for population growth, and
- How they account for technology-related reductions in GHG emissions

Table 1 below summarizes examples of GHG emissions metrics drawn from existing practice, as well as the strength and limitations of each example. This is not an exhaustive discussion of the metrics available or the strengths and limitations of each, but provides illustrative examples for some key metrics.

Table 1: Strengths and Limitations of Example GHG Emissions Metrics

Metric	Agencies that Use the Metric	Strengths	Limitations
Total on-road related CO_2 emissions (light duty + freight)	National Capital Region Transportation Planning Board at the Metropolitan Washington Council of Governments [32] Puget Sound Regional Council[33]	Accounts for the vast majority of GHG emissions Easy to assess progress toward national or State goals	Emissions from freight sources may be difficult for transportation agencies to address Outcomes may be affected by population growth
Light-duty vehicle CO_2 emissions per capita	Portland Metro[34]	Focuses on light-duty emissions, which are most responsive to transportation policies and strategies	Does not account for benefits of freight-related improvements
Light-duty CO_2 emissions per capita (removing effect of reductions from State fuel and vehicle policies)	All California MPOs[35]	Focuses on light-duty emissions, which are most responsive to transportation policies and strategies. Controls for improvements due to fuel efficiency that are outside of agencies' control	Does not account for benefits of freight-related improvements Requires additional analysis of technology-related reductions
Total on-road and off-road related greenhouse gas (GHG) emissions	Massachusetts DOT[36] Maryland DOT[37]	Accounts for all major sources of GHG emissions Easy to assess progress toward national or State goals	Emissions from freight and non-road sources may be difficult for transportation agencies to address. Outcomes may be affected by population growth and other exogenous factors.

Note: These examples only include combustion emissions. The strengths and limitations would be different if life- cycle emissions, alternative fuels, electrification, freight, or clean construction and maintenance practices were included.

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[32] Metropolitan Washington Council of Governments, Long Range Transportation Plan, Air Quality, Available at: http://www.mwcog.org/clrp/performance/air_quality.asp.

[33] Puget Sound Regional Council, Transportation 2040, available at: http://www.psrc.org/assets/4847/T2040FinalPlan.pdf.

[34] State established a target for a 20 percent reduction in per capita light-duty CO_2 by 2035. See: http://www.oregon.gov/LCD/CLIMATECHANGE/pages/metropolitan_greenhouse_gas_reduction_targets.aspx. Prior to establishment of this target, the Metro 2035 Regional Transportation Plan also included an aspirational target for total CO_2 emissions from on-road sources. See: http://library.oregonmetro.gov/files//2035_rtp_final_document_as_submitted_and_approved_by_dlcd_usdot_web.pdf.

[35] California Air Resources Board, Description of Methodology for ARB Staff Review of Greenhouse Gas Reductions from Sustainable Communities Strategies (SCS) Pursuant to SB 375, available at: http://www.arb.ca.gov/cc/sb375/scs_review_methodology.pdf.

[36] Massachusetts Department of Transportation (MassDOT), GreenDOT Implementation Plan, available at: http://www.massdot.state.ma.us/Portals/0/docs/GreenDOT/finalImplementation/FinalGreenDOTImplementationPlan12.12.12.pdf.

[37] Maryland Climate Action Plan: Maryland Department of Transportation Draft 2012 Implementation Plan, available at: http://www.mdot.maryland.gov/Office_of_Planning_and_Capital_Programming/Plans_Programs_Reports/Documents/Climate_Change_2011.pdf.

As Table 1 illustrates, each metric has its respective strengths and limitations. An area may also consider using a combination of total on-road (or transportation-related) GHG emissions and light-duty GHG emissions per capita. These measures complement each other well. A light-duty GHG emissions per capita measure can be easier for the general public to interpret and focuses attention on policies such as coordinated land use and transportation planning and multimodal travel options that may be State or regional policy priorities. A total transportation-sector GHG emissions measure allows the public and decision makers to see how transportation agency efforts fit into larger-scale GHG emissions trends and multi-sector climate change planning efforts. If a total transportation-sector measure or on-road emissions measure is selected, the emissions figures may be broken into components, such as emissions from freight and passenger travel, or from heavy-duty trucks, buses, and light-duty vehicles, to provide a more detailed understanding of emissions sources.

The metrics in Table 1 illustrate different approaches to address the relationship between GHG emissions metrics and the reduction strategies that are available to different transportation agencies. For instance, California MPOs use a light-duty per capita metric that controls for advances in alternative vehicles and fuels because existing State policies include light-duty fuel-efficiency standards, a low-carbon fuels standard, and measures to increase the efficiency of heavy-duty vehicles. The metric that MPOs use controls for the effect of these policies and focuses on GHG emissions that are most responsive to regional transportation and land use planning, and the metric is designed to encourage sustainable planning practices (e.g., efforts to support land use policies and transportation investments that reduce vehicle travel). On the other hand, Massachusetts DOT's GHG reduction target uses a metric account for a much broader scope of emissions, and MassDOT is considering GHG reduction strategies that address alternative fuels and light- and heavy-duty vehicle efficiency. In both cases, the agencies' GHG emissions metric reflects the scope of the emissions that they intend to address with their reduction strategies.

Establishing GHG performance metrics under California's Senate Bill 375

Under California's SB 375, every MPO in the State is required to develop a sustainable communities strategy (SCS), which is an integrated land use and transportation strategy that details its approach for meeting a regional GHG emission reduction target set by the State's Air Resources Board (ARB). The GHG reduction metric chosen by ARB is per capita greenhouse gas emissions from passenger vehicles and light-duty trucks. ARB's choice of metric illustrates how the policy goals of SB 375, interaction with state-level GHG reduction strategies, and other factors influenced its choices with respect to the key considerations discussed in this chapter.

- **Which sources are included**: In addition to reducing GHG emissions, SB 375 aims to better integrate regional transportation and land use planning. Since passenger vehicles and light-duty trucks are more likely to respond to changes in land use than heavy-duty vehicles, the GHG metric used by ARB focuses on emissions from these vehicles.
- **Geographic scope**: The Regional Targets Advisory Committee (RTAC), which developed the recommended metric for ARB, suggested a trip-end approach to accounting for emissions, but allowed that ARB, in consultation with the State Department of Transportation, Caltrans, may determine the extent to which an MPO has extent over interregional trips.[1] This choice reflects SB 375's emphasis on land use and transportation strategies that are likely to affect both internal and interregional travel, the fact that many of California's MPOs share borders with one another, and Caltrans' active role in analyzing interregional travel.
- **Accounting for technology**: ARB specifies a baseline set of assumptions about GHG reductions due to implementation of the State's fuel efficiency standards for passenger vehicles and its low carbon fuel standard. When calculating regional GHG reductions, MPOs only count reductions that exceed these baseline reductions in order to avoid double-county.
- **Ease of communication**: According to the RTAC, a per capita metric "is preferred for its simplicity, since it is easily understood by the public."

Source: California Air Resources Board, Recommendations of the Regional Targets Advisory Committee (RTAC) Pursuant to Senate Bill 375, Available at: http://www.arb.ca.gov/cc/sb375/rtac/report/092909/finalreport.pdf.

Other Supporting Measures

In addition to using a GHG metric, States or regions could consider related measures to support GHG reduction goals. One measure that has sometimes been identified for consideration as a proxy for GHG emissions is VMT or VMT per capita. Although this measure is not responsive to a wide range of transportation strategies that reduce GHG emissions, including operational strategies to improve traffic flow and eco-driving techniques, incentives to use alternative fuels or low-or zero-emission vehicles, and vehicle idling reduction, some areas may be interested in considering these measures. In particular, VMT can be a useful measure of progress or success when States or MPOs make a policy decision to focus on transportation demand management and land use strategies as a priority. Many MPOs also forecast these measures as a matter of course in analyzing plan alternatives.

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For instance, MARC, the MPO for the Kansas City metro area, chose two performance measures to support its goal related to climate change/energy use: VMT per capita and average number of vehicle occupants.[38] Washington State's House Bill 2815 established GHG emissions and VMT reduction goals and targets, including an 18 percent VMT per capita reduction below business–as-usual projections for 2020; 30 percent by 2035; and 50 percent by 2050.

The U.S. Environmental Protection Agency's (EPA) Guide to Sustainable Transportation Performance Measures also provides examples of a range of other metrics that might be considered.[39]

[38] Mid-America Regional Council, *Transportation Outlook 2040,* available at: http://www.marc.org/transportation/lrtp.htm.
[39] This resource is available at: http://www.epa.gov/smartgrowth/pdf/Sustainable_Transpo_Performance.pdf.

6. Analyzing Trends and Setting Targets

While a performance measure itself provides a metric for evaluating outcomes, a PBPP approach requires a transportation agency to identify trends (directions for impacts) or targets (specific levels of performance desired to be achieved within a certain timeframe) for each performance measure to provide direction to strategy analysis and performance tracking. There are multiple ways in which targets can be set:

- Policy-based
- Consensus-based
- Analysis-based

Regardless of the approach, it is important to first understand baseline conditions. For GHG emissions, the baseline should provide information on the key sources of emissions and factors affecting emissions. Baseline conditions will include past trends and current performance levels. In addition, it is important to conduct analysis to understand expectations for future performance.

Developing a Baseline: Looking Back and Looking Ahead

A first step for agencies in developing a baseline is to develop an inventory of past and/or current GHG emissions (such as estimating an inventory of on-road CO_2 emissions in 2010) and a long-range forecast of CO_2 emissions (20, 25 or 30 years out), and then translating that inventory into the selected metric, if necessary. The long-range forecast period should ideally correspond with the end date of the long-range transportation plan, and could potentially include developing estimates of CO_2 emissions at a few mid-range points in time (for instance, in 10-year increments).

Many States have already developed GHG inventories, typically relying on fuel-based methodologies. A useful GHG inventory will provide information not only about total GHG emissions, but can provide information on the key sources of emissions (e.g., passenger cars, trucks) in order to inform policy and investment analysis. Just as detailed data on the sources and locations of crashes is helpful to develop effective countermeasures to improve safety, understanding the sources of GHG emissions is helpful in identifying potential strategies. Some more sophisticated inventory analyses also provide information on the locations of emissions (e.g., either by road link or assigning emissions to origins and destinations).

Depending on the organization's resources, modeling can be conducted to develop a baseline (or business as usual) forecast for the future. This forecast can be used as a basis for comparing emissions under alternative scenarios. This modeling can be relatively sophisticated. Having a business as usual scenario is important in understanding where emissions are expected to be headed and what level of reduction may be realistic to achieve. Given that PBPP is an iterative or cyclical process, performance that is monitored may become the new base line against which results from the next performance cycle are reported.

It is important to note that particularly at the State level, GHG inventories are often calculated based on fuel consumption data. As noted earlier, one limitation of a fuel-based inventory is the potential disconnect between the place of fuel sales and the location of the travel activity and/or generators of emissions. For instance, Maryland DOT has found that fuel sales do not provide as accurate a basis for estimating GHG emissions as VMT-based methods, given the amount of cross-border traffic, and has switched to developing inventories and forecasts based on VMT data and the MOVES model.[40] Another issue is that fuel-based inventories often do not connect well with future emissions forecasts, which are typically developed using VMT forecasts and emissions models. This has been noted as an issue by State DOTs, including the Vermont Agency of Transportation, which had a transportation GHG inventory developed based on fuel consumption data and was trying to reconcile it with its forecasts based on travel data.[41]

Considerations for Developing a Historic Baseline GHG Inventory

There are a number of key considerations for developing a historic inventory, which are discussed below.

- *Boundaries* – Define the geographic boundaries of analysis. Some MPOs may have modeling areas that are larger than the geographic boundary of the MPO. This may affect the ease with which existing data can be utilized. In some cases, agencies may wish to account for emissions that are generated by external trips beginning or ending outside of the region separately.
- *Scope* – Decide which emissions source categories (e.g., on-road sources only, or all transportation sources) and subcategories (e.g., light-duty vehicles, heavy-duty vehicles, buses) should be included, as well as which specific GHGs (CO_2 only, or also N_2O and CH_4).
- *Analysis method* – Depending on the data available and purpose of the inventory, choose a top-down (fuel-based), bottom-up (VMT-based), or hybrid approach. The geographic scope tends to influence the type of method that is selected for GHG analysis, based on data availability. At the State level, fuel-based methods are often used given the availability of State-level fuel consumption data, whereas at the MPO level, fuel sales data may not be available.
- *Baseline year* – Select a baseline year to provide a benchmark to compare progress going forward, considering whether data for that year are available, the chosen year is representative, and the baseline is coordinated with baseline years used in other inventories.[42] (Note: In some cases, legislation or executive direction will specify the baseline year.)

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[40] See Chapter 2, "2006 Baseline and 2020 BAU Forecast Greenhouse Gas Emissions Inventory Update," from Maryland DOT's *2011 Climate Action* Plan available at http://www.mdot.maryland.gov/Office_of_Planning_and_Capital_Programming/Environmental_Planning.html.

[41] Potential Methods to Improve Vermont's Transportation Greenhouse Gas Inventory. Prepared by ICF International, August 30, 2010.

[42] For a more detailed discussion of how to select a baseline year, refer to the "Inventory Development" section of Chapter 2.3 in FHWA's *Handbook for Estimating Transportation Greenhouse Gases for Integration into the Planning Process*, available at: http://www.fhwa.dot.gov/environment/climate_change/mitigation/resources_and_publications/ghg_handbook/index.cfm.

- *Data limitations* - If necessary data are incomplete or have limitations, as will often be the case, it is important that all involved are aware of the limitations and assumptions. Having complete documentation of methodologies used is important when comparing inventories or forecasts conducted in future years to the current estimate.

Potential types of emissions that could be 'counted' or assigned to a State or region

- Emissions associated with fuel sold within the boundaries. This is the approach commonly used within fuel-based inventories; however, it raises some questions about whether a State or region should be responsible for fuel that is sold in an area but is used outside of it. From a performance-based planning perspective, an agency may want to focus its inventory on those travel activities that they have the greatest level of influence over.
- Emissions from travel on the transportation system within the boundaries. This is the approach that is applied for transportation conformity purposes - emissions from all travel on the roadway network, whether due to local traffic or interstate through trips, are analyzed and reported.
- Emissions generated by households and/or businesses within the boundaries. A State DOT or MPO might instead be interested in focusing on GHG emissions due to the transportation activity of residents living or working within their jurisdictional boundaries (possibly including business and freight travel, as related to household goods consumption), taking out the effect of "through trips." This can be useful for areas that would like to allocate emissions to particular jurisdictions within their planning area (e.g., allocating transportation emissions to each county within a State). In this case, it is necessary to understand trip origins and destinations, and assign a portion of emissions to each, while removing the effect of trips that entirely pass through an area.

There are some advantages and challenges to each approach, so it will be important to agree upon what is the most desired way of counting emissions.

Considerations for Developing a Business-as-Usual GHG Forecast

Future emissions levels could differ from existing conditions for many reasons. It could be higher, for example, because VMT of the target population is rising. Or it could be lower because the vehicle fleet is becoming cleaner. While simple in concept, establishing an emissions baseline for the future, or "business-as-usual" forecast, can be challenging because it requires assumptions about travel behavior, vehicle technology and fuels, and other factors that affect emissions.

Some considerations for developing a baseline forecast are discussed below.

- *Forecast year(s)* – Forecasts may be developed for one or more milestone years in the future. The selection of milestone year(s) may be influenced by (a) legislative or executive branch GHG targets and laws and (b) synchronizing with planning timeframes of the State or area. Also, consider whether to analyze GHG on a cumulative basis, rather than for a specific forecast year, since climate change impacts are based on cumulative GHG, over decades.
- *Analysis method* – Depending on the data available and the purpose of the forecast, select a method that matches the appropriate level of detail and accuracy for the analysis purpose.

- *Additional strategy analyses* – Depending on the sophistication of the analysis method and existing modeling tools (e.g., the level of sophistication of the travel demand model), additional "off model" analyses may need to be conducted to adjust the forecast.
- *Results* – Clearly document the results, including assumptions and any limitations or caveats. Identify key areas of sensitivity affecting results

Key Tools and Methods to Consider

There are a variety of tools and approaches available to estimate baseline GHG emissions. These include both tools for estimating historic emissions as well as tools for forecasting baseline emissions into the future. More detail on all of these tools and methods is available from FHWA's *Handbook for Estimating Transportation GHGs for Integration into the Planning Process*, available at: http://www.fhwa.dot.gov/environment/climate_change/mitigation/resources_and_publications/ghg_handbook/index.cfm.

Fuel-based Methods – Fuel-based methods calculate GHG emissions based on fuel consumption data, such that emissions estimates are associated with the location of fuel sales. The most commonly used tool for developing a fuel-based inventory at the State level is EPA's State Inventory Tool (SIT). The SIT is a spreadsheet model that helps States to estimate their carbon dioxide (CO_2) emissions from all sectors (e.g., on-road gasoline, on-road diesel, aviation, rail, marine, and natural gas/other). It provides the option of using State-specific data or using default data that is generated by Federal agencies and some other sources. Based on its structure, the SIT approach is most appropriate for developing a transportation GHG inventory as part of a broader statewide inventory development process for all sectors, and for statewide analyses that do not require detailed breakdowns of transportation GHG emissions by transportation mode or by local jurisdiction. From a performance-based planning perspective, it is desirable to be able to disaggregate on-road vehicle emissions by vehicle class and geography (through trips, etc.). State agencies working with SIT have considered implementing approaches to disaggregate their on-road emissions further so they can be linked more closely with their existing transportation planning models and processes.

Fuel projections can be used to develop simple forecasts of CO_2 emissions, and EPA's State Inventory Project Tool is a useful tool for these calculations. However, it relies largely on projections of fuel consumption reported in the Energy Information Administration's *Annual Energy Outlook* by sector and region, and does not account for transportation investment strategies, or other characteristics, such as fleet composition changes.[43] Some States have developed vehicle fuel forecasting methods or tools, which can be used for GHG forecasts. Although State DOTs often estimate future fuel sales as part of their fuel tax revenue projections, in many cases, these methods are simplistic and do not account for many factors that influence GHG emissions.

[43] "Annual Energy Outlook 2011 - Transportation," U.S. Energy Information Administration. http://www.eia.gov/forecasts/aeo/sector_transportation.cfm.

VMT-based Methods - VMT-based methods involve estimating vehicle travel (and its operating characteristics for more accuracy) and then applying emissions factors or an emissions model, such as EPA's MOVES Model, to calculate GHG emissions. States can develop VMT based GHG emissions inventories by using VMT estimates from the Highway Performance Monitoring System (HPMS) and applying emissions factors. HPMS forecasts of traffic can also be used to develop projections of VMT. Alternatively, States could extrapolate trends by functional class, using regression to correlate changes in the population to VMT, or other types of statistical analyses.

Most MPOs use network models for forecast VMT. Network models have the advantage of being able to capture changes related to population and employment growth as well as transportation network or system changes. Network models also allow for testing of both transportation demand and supply in an integrated model. Network models are commonly used by MPOs, their model framework is well understood, and the inputs they require are generally available. It is important to recognize, however, that many models are not sensitive to or sufficiently complex to address strategies that may be considered to reduce GHG emissions, including certain land use policies, demand management strategies, and operational strategies.

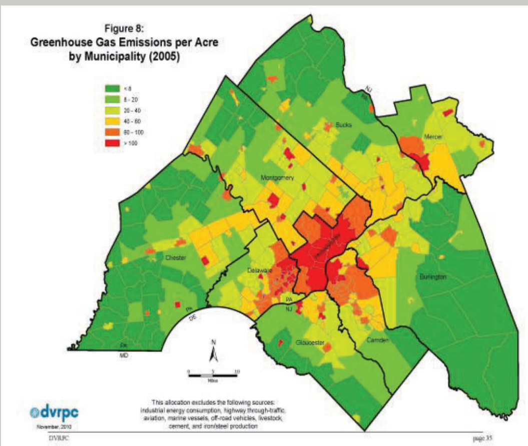
There are multiple approaches for converting VMT forecasts into emissions. Capturing changes in vehicle technology and improvements in the fuel economy of future vehicles is critical to creating an accurate forecast. Estimating how changes in vehicle speeds may affect emissions is also important for capturing how changes in traffic levels and infrastructure investment may affect future GHG emissions.

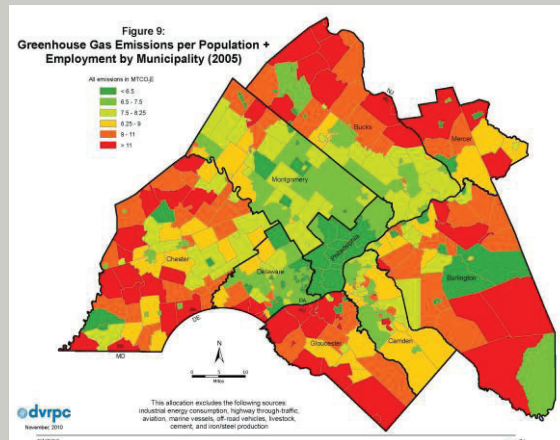
A more simplified approach is to use sketch planning methods to develop inventories and forecasts, such as building estimates of emissions using odometer, household travel survey or land use data. These VMT methods are generally intended for calculating household GHG emissions (not freight). They also are largely intended for developing inventories, although extrapolations of historical trends can be made to develop forecasts, recognizing a high degree of uncertainty in these results.

Delaware Valley Regional Planning Commission (DVRPC) GHG Inventory Analysis

One approach to developing a baseline GHG inventory using a transportation demand model can be seen in the inventory developed by DVRPC, the MPO for the Philadelphia metro area. DVRPC developed a regional GHG emissions inventory that relies on travel demand model output to allocate GHG emissions to different traffic analysis zones.

HPMS data was used to determine a VMT total. Through traffic was estimated based on the travel demand model trip table that shows trips with origins and destinations outside the region. VMT from through traffic was subtracted from total VMT to focus the analysis on travel within the region. VMT was then apportioned to municipalities based on trip origins, destinations and trip length. Emissions were mapped per acre, per population and per employee.





The map above to the left shows emissions per acre, and indicates that GHG emissions are higher in Philadelphia's urban core. If emissions for trips are allocated 50 percent to the trip origin and 50 percent to the trip destination, the map on the right shows that emissions are higher on a per population and per worker basis in the suburban and exurban areas around Philadelphia. The DVRPC inventory helps make the case for the role of denser land use development in reducing the GHG emissions intensity of development in the region. DVRPC's inventory is available at: http://www.dvrpc.org/EnergyClimate/inventory.htm

VMT based approaches use emission factors, generally expressed in terms of grams per mile, grams per hour, and grams per trip end. For a given pollutant, emission factors will vary according to the vehicle type (weight), engine technology, fuel type, vehicle model year, speed, and roadway type. Other factors affecting emissions rates include ambient temperature, inspection and maintenance programs, and vehicle deterioration.

EPA's MOVES model is the most robust tool available to produce estimates of on-road transportation GHG (and other) emissions. The model estimates energy consumption and emissions, including atmospheric CO_2, CH_4, N_2O, and CO_2e. MOVES can estimate emissions at the national, regional, or county, scales and for annual or shorter periods of time. The model itself requires many inputs, and

although defaults are available for most factors, defaults are generally poor substitutes for locally specific inputs. Inputs to MOVES include data on vehicle population, fuel type, and VMT. The model works by simulating actual vehicle drive cycles, including the effect of travel at different speeds and vehicle power loads. Sensitivity to vehicle operating conditions is important when examining transportation plans and policies, such as new highway capacity investments, congestion pricing, and other strategies that affect vehicle speeds and operating conditions.

Identifying Desired Levels of GHG Reduction

Desired outcomes and targets may be expressed in three primary ways:

- **Directional – Identifying a direction of impacts desired; in the case of GHG emissions, this would be a reduction in emissions.** Practitioners from State and regional transportation agencies may be hesitant to set specific targets for GHG emission reduction, just as they are often hesitant to set targets for other measures, given concerns about either setting targets too low as to seem unambitious or too high so that they are unattainable. Agencies also are often concerned about the potential ramifications – including public perception – of not meeting targets. Consequently, a simple step is to identify a desired direction to reduce GHG emissions. While setting only a direction for the desired impact does not provide specificity, it can serve as a basis for comparing alternative investment/policy scenarios. It is important to note that in areas with fast growing populations, reducing GHG emissions from on-road sources may be challenging. However, setting a desired direction sends a signal from higher levels of government that decision-makers are interested in committing to GHG reductions.

- **Aspirational – Setting targets based on policy priorities or to signal an issue's importance to the community,** often prior to conducting a detailed analysis to determine actual feasibility. Many of the States and regions that have already begun to set targets for GHG emissions reductions through climate action plans or related policies have set aspirational targets. The following States have established specific statewide GHG emissions targets: Arizona, California, Colorado, Connecticut, Florida, Hawaii, Illinois, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New Mexico, New York, Oregon, Rhode Island, Vermont, and Washington.[44] Although many of these aspirational targets address total GHG emissions from all sources (transportation and otherwise), setting an aspirational target can signal the importance of climate change to policy-makers at the State, regional, or local levels, as well as relevant interest and advocacy groups and the public, all of whom may later have some involvement in project and investment prioritization. Setting aspirational targets may also emphasize the importance of multiple factors – transportation investments, land use, vehicle

[44] Center for Climate and Energy Solutions, http://www.c2es.org/us-states-regions/policy-maps/emissions-targets.

technologies, fuels, transportation operations, etc. – in reaching targets, since it may be impossible for transportation investment strategies alone to reach the target.

"Target zero" initiatives focused on eliminating roadway fatalities have brought together a wide range of stakeholders involved in traffic safety, including transportation agencies, law enforcement, and public health, to address the causes of crashes. Similarly, an aspirational target for reducing GHG emissions may help to encourage greater partnership among transportation planning agencies, operating agencies, environmental agencies, and policy-makers to consider the wide range of strategies needed. For instance, the Denver Regional Council of Governments (DRCOG)'s board has set a per capita GHG reduction target of 60% below 2005 levels by 2035 from the transportation sector, as well as reduction in "drive alone" commutes and per capita VMT. The GHG reduction target was based on the State GHG reduction targets, but not on a systematic analysis of what was feasible.

- **Analytically-based – Accounting for available resources, trends, policies or strategies in consideration, and other factors that may affect performance, and setting a target that is believed to be attainable**. Developing analytically-based targets requires conducting analyses of potential strategies, understanding available funding, and considering the various factors that influence emissions. This analysis may find that it is not realistic to reduce GHG emissions in the short-term but that long-term policies, such as land use changes and technological changes, can have more notable effects. For instance, the Metropolitan Transportation Commission (MTC) of the San Francisco Bay Area included a set of ambitious targets in its 2035 Transportation Plan, adopted in 2009. These targets were aspirational, and among others, included a target "to reduce carbon dioxide emissions to 40% below 1990 levels by 2035." The Plan clearly identified gaps between aspirational targets and expected outcomes. In the subsequent development of Plan Bay Area, MTC worked with the State of California to develop analytically-based targets in relation to State requirements. These targets call for MTC to demonstrate that its long range plan will reduce per-capita CO_2 emissions from cars and light-duty trucks 7% by 2020 and 15% by 2035, compared to 2005 levels. As was the case in California in the preceding example, realistic targets are often constrained by the decisionmaking status quo and the technical and/or political resources available to set policies or implement strategies.

States and regions that are assessing GHG emissions and setting reduction targets for the first time can refer to existing studies that discuss the magnitude of emissions reduction they might be able to expect as the result of some common strategies before setting targets. There will be an opportunity later in the planning process to revise these targets based on any significant changes in policy, technology, or demographic forecasts, but setting a strong target at the outset helps provide direction for strategy implementation.

The Genesee Transportation Council (GTC) is the MPO that includes nine upstate New York counties and the City of Rochester. The GTC includes fifteen performance measures in its Long Range Transportation Plan (LRTP). Of these fifteen performance measures, one is directly related to GHG emissions reduction (e.g. CO_2e) and one related to direct energy use. Additionally, the LRTP includes four mobility and three accessibility measures, all of which are focused on managing future travel demand. GTC has adopted directional targets in its performance measurement process based upon benchmarks established for each measure. For example, there are estimated to be 11,385 tons/day of CO_2e in the region with a goal of decreasing that amount. These emissions were estimated by post-processing volume and speed data from the GTC Travel Demand Model using methodologies developed in conjunction with NYSDOT. Another example of a directional target in the GTC LRTP is the transit on-time performance measure where the goal is to increase the current 84% on-time performance on transit.

See GTC's LRTP for more information: http://www.gtcmpo.org/docs/LRTP.htm.

Choosing a Timeframe for Analysis

Identifying a timeframe for targets helps determine the target's level of achievability. Analysis periods to be considered include:

- Long-range – twenty or more years in the future
- Mid-range – ten years in the future
- Short-range – three to five years in the future

Determining the time horizon over which outcomes are measured is also important. Given the long lag time for many strategies to take effect – particularly land use changes and large scale transportation investments – a long-term outlook may be particularly useful for GHG emissions and fits within the long range planning process. However, mid-range or short-range timeframes could also be considered. For instance, MPOs addressing conformity might wish to set targets in relation to milestone years. Given the important role of exogenous factors, such as fuel prices and economic growth, which are volatile and have important impacts on GHG emissions, short-range targets may not be as helpful. Thus, it is important to ensure that short-term expectations are not derived in a linear fashion from long-term targets, since programs may take several years to implement and their impacts can increase over time.

7. Identifying Strategies, Analyzing Alternatives, and Developing Investment Priorities

In a PBPP process, performance measures and targets are used to inform decisions on investments and policies. To do so, an agency needs to identify and analyze strategies to assess their anticipated benefits relative to established targets. This information will be valuable to inform decisions on investments and policies that are incorporated into the LRTP and TIP and STIP, as well as potentially to inform broader policy decisions (e.g., related to vehicle technologies and fuels).

Approaches for Using GHG Performance Information in Planning

There are two primary approaches that can be used to integrate GHG performance measures in the plan development process: analyzing GHG performance along with other performance measures during LRTP development, or conducting a focused analysis of GHG reduction strategies that supports the LRTP.

Analyze GHG Performance Together with a Range of Other Performance Measures within LRTP Development

As part of LRTP development and analysis, MPOs will frequently develop alternative investment packages and then conduct modeling analysis to compare the performance of different alternatives across several metrics. For instance, an MPO may develop alternative packages with different emphasis areas, such as increased investments in transit, highway preservation, or management & operations strategies, together with alternative land use policies, and compare the performance across multiple metrics, including mode share (e.g., transit, walk/bike, drive alone), congestion (e.g., vehicle hours of delay), and emissions of criteria pollutants and GHGs. This analysis will inform policy makers of what future GHG emissions are expected to be under different investment scenarios, and allow decision-makers to make informed choices while considering the range of performance outcomes of importance to the region.

Conduct a Focused Analysis of GHG Reduction Strategies that Supports the LRTP

Another approach that a State DOT or MPO could apply is to conduct a focused analysis of transportation GHG reduction strategies to understand key factors affecting GHG emissions and effective strategies, in order to feed into decisionmaking for the LRTP.

Transportation agencies can consider a wide range of GHG reduction strategies, including land use planning, promoting advanced vehicle technologies, encouraging the use of alternative fuels, improving transportation system operations, implementing transportation demand management programs and reducing the carbon footprint of transportation agencies themselves.[45] Specific strategies could

[45] http://www.ops.fhwa.dot.gov/tdm/index.htm http://www.ops.fhwa.dot.gov/publications/fhwahop12035/index.htm.

incorporate alternative fuel vehicle infrastructure investment, pricing programs, improved transit services, investments in improved vehicle operations such as through Intelligent Transportation Systems (ITS), accessibility/mobility strategies, walkable communities, provision of transportation alternatives to driving and transit oriented development. Freight strategies might include truck climbing lanes, truck-stop electrification or other projects.

There are a number of resources to help practitioners assess potential strategies. These include the following:

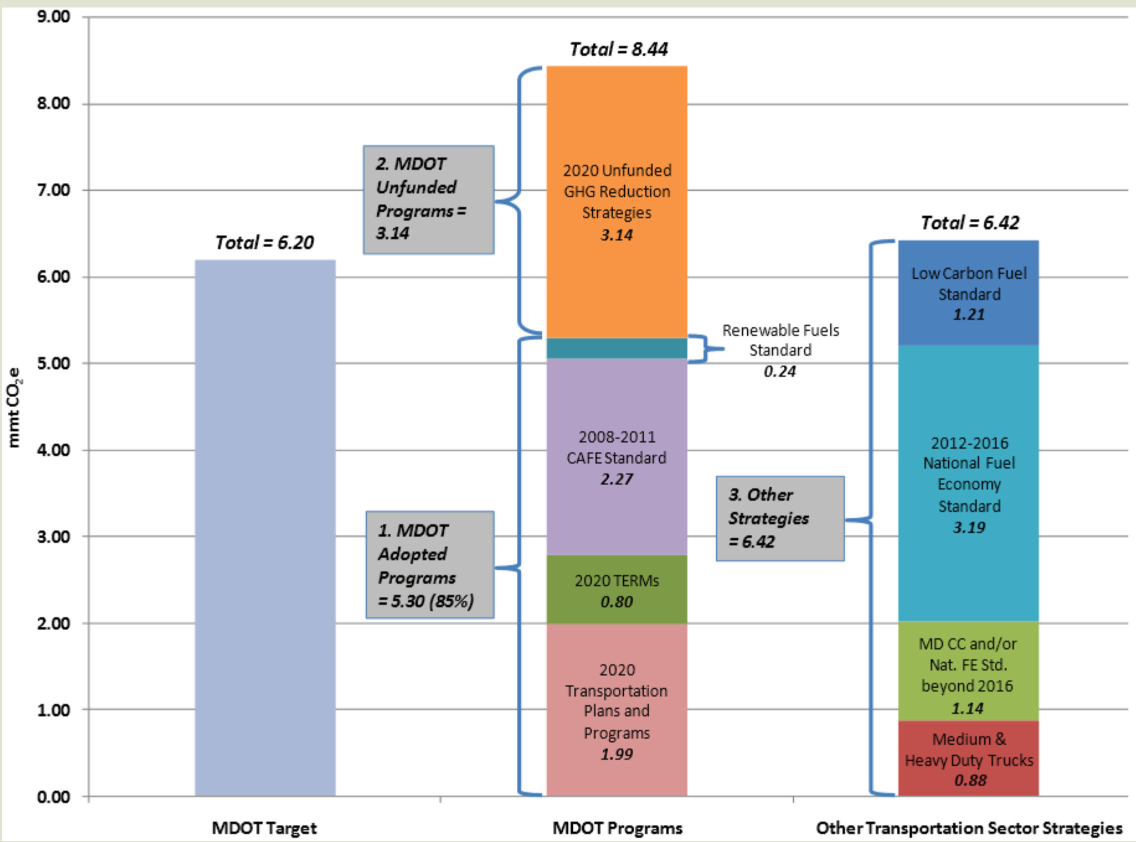
- The U.S. DOT has developed a Transportation Climate Change Clearinghouse that provides information on GHG mitigation strategies and how to evaluate them, as well as links to a wide range of studies and other resources. http://climate.dot.gov/ghg-reduction-strategies/index.html
- FHWA has developed the Energy and Emissions Reduction Policy Analysis Tool to assist States and regions in estimating the impact of transportation strategies. http://www.planning.dot.gov/FHWA_tool/
- FHWA has developed a *Handbook for Estimating Transportation Greenhouse Gases for Integration into the Planning Process*. This resource provides summary information on techniques, methods and models that can be used by planners to estimate GHG emissions impacts of different transportation strategies. http://www.fhwa.dot.gov/environment/climate_change/mitigation/resources_and_publications/ghg_handbook/chapter01.cfm
- EPA has developed the report Analyzing Emission Reductions from Travel Efficiency Strategies: A Guide to the TEAM Approach http://www.epa.gov/otaq/stateresources/policy/420r11025.pdf

A focused analysis of GHG reduction strategies may be particularly helpful to State DOTs, since their LRTPs often set out a key policy direction and strategies, but traditionally have not involved identifying and modeling specific project investments. Although not required by law, this approach could be similar to the approach used in the development of a Strategic Highway Safety Plan (SHSP). In developing an SHSP, a focused safety analysis is conducted, using a data-driven process to understand the source of problems at a detailed level, identify potential solutions (i.e., safety countermeasures), assess the effectiveness of alternative strategies, and prioritize strategies. By bringing together a wide range of stakeholders that play a role in safety – transportation agencies, law enforcement, emergency medical services, etc. – and focusing broadly on the sources of problems, this approach helps support collaborative efforts. If implemented effectively, a transportation-focused Climate Action Plan or sustainability planning effort could function in a similar way. This approach can help to support informed investment decisionmaking and may serve as a catalyst for dialogue between decision-makers at the State and local levels to consider strategies (e.g., land use, incentives, pricing) that may not be traditionally considered in transportation planning by State DOTs.

An example of a State DOT led climate strategy analysis is work conducted by Maryland Department of Transportation in developing its Climate Action Plan.

Maryland: State Climate Action Plan

Maryland is a State with significant climate change vulnerabilities, particularly sea level rise, given its many tidal coastlines. In 2009, the Maryland General Assembly passed the Greenhouse Gas Emissions Reduction Act of 2009, which required the State to develop and implement a climate action plan to reduce GHG emissions by 25 percent by 2020 (from a 2006 baseline). Maryland DOT was designated by Maryland Department of Environment (MDE) as an implementing agency for six transportation and land use mitigation and policy options. In 2012, Maryland DOT published an Implementation Plan to support its achievement of a 6.2 mmt CO_2e reduction by 2020 (set by MDE). The figure below summarizes GHG emissions expected from the State's 2011-2016 capital program, as well as MPO programs in the State. Maryland DOT continues to work with MDE and other State agencies to achieve the legislature's statewide GHG reduction goals.



For more information, see:
http://www.mdot.maryland.gov/Office_of_Planning_and_Capital_Programming/Plans_Programs_Reports/Documents/Climate_Change_2011.pdf

At the MPO level, the National Capital Region Transportation Planning Board (TPB) at the Metropolitan Washington Council of Governments conducted a "What Would it Take?" analysis in 2010 to evaluate

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the types of strategies that would be required to meet regional climate change mitigation targets, including GHG emission reductions.[46] The analysis required a GHG inventory and forecast, which was created using a travel demand model to forecast vehicle miles traveled (VMT) for the years 2005, 2010, 2020, and 2030, and applied MOBILE6.2-generated CO_2 emissions factors to generate CO_2 emissions totals.[47] The analysis addressed a wide range of strategies, including transit investments, eco-driving, and operations strategies.

The Atlanta Regional Commission (ARC), Atlanta's MPO, performed a scenario analysis to compare the long range plan forecasts with various transportation investments and vehicle technological improvements in an effort to understand what actions would be required to reduce on-road GHG emissions to 1990, 2000, or 2010 levels.[48] ARC's analysis used a 4-step travel demand model and MOBILE6, the previous EPA emissions model, to model land use scenarios that described different potential growth patterns.[49] Other examples are provided by California MPOs, which have conducted extensive analysis to show which strategies can be implemented and investments made to reduce light-duty GHGs above and beyond what will be achieved through vehicle technologies and fuels.[50]

An important element of this approach, however, is that it should not be just a stand-alone analysis. The GHG analysis and strategy assessment should directly inform and support investment decisions in the LRTP.

Identifying the Most Appropriate GHG Reduction Strategies

A wide suite of strategies are available to reduce GHG emissions from transportation. It is important that States and MPOs identify the key drivers of GHG emissions in their areas and then analyze potential GHG reduction strategies to assess potential effectiveness in their specific State or regional circumstances. Some of the types of transportation-related GHG reduction strategies that may be advanced by States and MPOs are briefly described below.

VMT Reductions - Light-duty Vehicle Strategies

GHGs from light-duty vehicles can be further reduced beyond what will be achieved through technological developments and regulatory programs, primarily through reductions in VMT influenced by strategies and programs that support travel alternatives. These strategies include:

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[46] MWCOG, "What Would It Take?" Available at: http://www.mwcog.org/clrp/elements/scenarios.asp.
[47] FHWA, "Handbook for Estimating Transportation Greenhouse Gases for Integration into the Planning Process."
[48] Atlanta Regional Commission's PLAN 2040 and associated documents. Available at: http://www.atlantaregional.com/plan2040/documents--tools.
[49] In the time since ARC conducted the scenario analysis using MOBILE6, the EPA has developed an updated model, MOVES. FHWA, "Handbook for Estimating Transportation Greenhouse Gases for Integration into the Planning Process."
[50] Metropolitan Transportation Commission's Climate Change website. Available at: http://www.mtc.ca.gov/planning/climate/.

- **Carpooling and vanpooling programs** that provide an option for motorists to split the costs and externalities of driving alone
- **Bicycling and pedestrian improvements** that encourage greater multi-modal road use
- **Transit improvements**, which provide greater options for motorists to leave their cars at home
- **Teleworking programs**, which give employees the choice to work from home or choose an alternate travel schedule
- **Pricing strategies,** including road pricing, parking pricing, and including Pay as You Drive insurance, influence motorists to drive less and use alternative modes more
- **Land use planning and urban design**, which can reduce trip length, and increase use of transit and non-motorized modes
- **Outreach and education** to increase awareness about the use of alternative modes, the option of teleworking, and other choices that reduce personal costs and GHG emissions from light-duty vehicle travel
- **Incentive programs** to influence more motorists to drive alone less often

By creating more transportation options and influencing travel behavior, these strategies also support other objectives in most regions including improving mobility and travel choices, reducing emissions, developing livable communities, improving access for bicyclists, and improving pedestrian safety. Therefore, such strategies complement and support other regional and/or State objectives.

Vehicle/Systems Operations Strategies

There are a number of actions that State DOTs and MPOs and local communities can take to reduce GHG from transportation system operations. These include the following strategies:

- Managing speed (35-55 MPH is optimal)
- Speed limits/enforcement
- Eliminating bottlenecks
- Smoothing traffic flow
- Improving signal timing
- Roundabouts
- Reducing car and truck idling
- Work zone management to smooth flow
- Congestion pricing
- Encouraging eco-driving

Several of these strategies are routinely included in MPOs' and State DOTs' long range plans because they support other regional and/or State goals and priorities. While these strategies reduce GHG emissions, it is important to recognize that some of them, such as eliminating bottlenecks and improving traffic flow, may facilitate additional vehicular travel that may offset GHG reductions in the long term.

Freight Strategies

Heavy-duty truck GHG emissions are growing faster than other sources of transportation GHGs, and constitute a significant portion of total on-road emissions. An evaluation of GHG emissions from heavy-duty vehicles in seven States found that while the heavy-duty VMT accounted for a relatively small share of total in-state VMT, heavy-duty CO_2 emissions accounted for 20 to 37 percent of total on-road emissions in these States.[51]

MAP-21 established a national freight policy that requires the U.S. DOT to establish a primary freight network of up to 300,000 miles, and requires the development of a National Freight Strategic Plan. With this new focus on freight planning, there may be additional opportunities to address freight-related GHG emissions. Freight strategies that have been identified in various State climate action plans (and some of which are routinely included in State and/or MPO Long Range Plans) are listed below.[52]

- Anti-idling programs
- Truck-stop electrification
- Speed limit enforcement
- Freight villages/consolidation centers
- Feeder barge container service
- Bottleneck reduction
- Traffic flow improvements
- Pre-clearance at scale houses
- Truck driver training
- EPA SmartWay upgrade kits, loans and diesel retrofits
- Improvements to highway grade crossings
- Efficient intermodal facilities
- Incentives to retire older trucks
- Freight logistics improvements
- Shifting freight from truck to rail
- Technologies (Hybrid power trucks; low-viscosity lubricants; single side-base tires; automatic tire inflation systems)

[51] An evaluation of VMT and on-road CO_2 was conducted for seven states (Michigan, California, Nevada, Maryland, South Carolina, Pennsylvania, and Idaho) and eight metropolitan regions (Atlanta, Denver, Salt Lake City, Chattanooga, Washington, DC, San Francisco, Youngstown, OH, and Burlington, VT). The evaluation found that in the seven states, heavy-duty vehicles accounted for 7%, 8%, 9%, 10%, 10%, 11%, and 18% of total VMT in Michigan, California, Nevada, Maryland, South Carolina, Pennsylvania, and Idaho, respectively. The evaluation also found that heavy-duty vehicle travel accounted for 20%, 21%, 28%, 22%, 26%, 28%, and 37% of total on-road CO_2 emissions in Michigan, California, Nevada, Maryland, South Carolina, Pennsylvania, and Idaho, respectively. This analysis was conducted by ICF International using data from FHWA and these states.

[52] Detailed information on strategies is available in NCHRP 20-24(59) Appendix C, available at: http://climatechange.transportation.org/pdf/nchrp_2024_59_final_report_031309.pdf.

Fuel Efficient Vehicle Technologies and Alternative Fuels

The introduction of more fuel efficient vehicles and alternative fuels can reduce GHG emissions. While vehicle fuel efficiency standards have been primarily implemented at the Federal level to date, California has the legal authority to adopt more stringent vehicle technology standards to reduce air emissions. Other States may adopt California standards. States can influence the adoption of new vehicle by purchasing these vehicles for their own fleets. Tax breaks or subsidies for new vehicle technologies may also be adopted at the State or regional level. New vehicle technologies may also be given other special preferences. For instance, California law allows single-occupant use of high occupancy vehicle (HOVs) lanes by certain qualifying clean alternative fuel vehicles.

The use of low carbon fuels is another important strategy that can be promoted at the State or regional level to reduce GHG emissions. States and localities have been involved in promoting a range of alternative fuels, including natural gas (CNG, LNG), propane, biofuels (ethanol, biodiesel) and electricity. States and regions can promote the installation of alternative fuel filling stations or electric vehicle charging stations. A number of agencies have prepared electric vehicle readiness studies to plan for electric vehicle use. Alternative fuel mandates in some States have been used to require the mixture of biofuels, such as biodiesel, into the fuel supply. Lower fuel tax rates on alternative fuels may also provide an incentive for their use. California has adopted a low carbon fuel standard that provides a fuel-neutral mechanism to promote lower carbon fuel use.

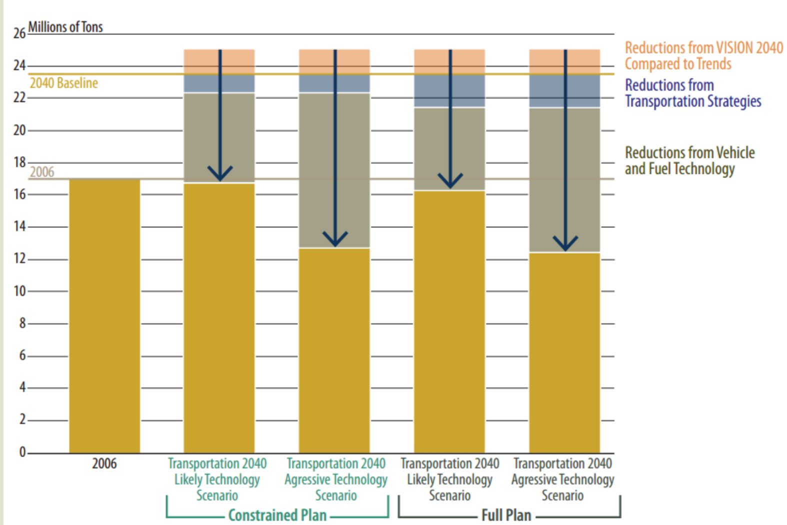
Developing an Investment Plan: Analyzing GHG Emissions to Inform Investments and Policy Priorities

As noted earlier in the section on developing a baseline, GHG emissions forecasts are typically developed using a combination of travel demand forecasting models and emissions models. Scenario planning is a tool that can also be important for emissions forecasts, and allows for the comparison of different investment plans on State and/or regional objectives and goals. Scenario planning is fairly common at the MPO level, as MPOs use their travel demand models to assess alternative packages of investments. In general, scenario planning is more useful when sub-area performance measures are also reported because the more flexible the model, the easier it is to use as a tool for answering particular questions that arise during the public involvement process.

At the State level, a challenge is that many LRTPs are largely policy-documents or corridor-based, and even if investments are identified, forecasting models may not be available to analyze investments. Still, State DOTs could conduct analyses of alternative policies and strategies, much like the analyses that have been conducted by States as part of Climate Action Plans.

The Puget Sound Regional Council (PSRC) developed its Long Range Regional Plan using five different scenario alternatives. Climate change was a factor considered in developing scenarios, but there were also many other components. Through the public participation process, climate change became such an important priority that GHG reduction strategies were included in the final scenario plan, and GHGs were used in the prioritization criteria. The most recent long range plan, Transportation 2040, has a four part strategy that includes Land Use, Transportation Pricing, Transportation Choices, and Technology. The results of the investments and strategies contained in Transportation 2040 are illustrated in the figure below. The combination of the four-part strategy results in a range of emissions reductions (between 5 percent likely technology scenario and 28 percent aggressive technology scenario) below 2006 modeled emissions. As compared to the 2040 Baseline trend, the preferred alternative results in emissions reductions between 31 percent and 48 percent.

FIGURE 18. Greenhouse Gas Emissions (CO2 Emissions in Millions of Tons)



Source: Puget Sound Regional Council, *Transportation 2040,* Chapter 3 and Appendix L, available at: http://www.psrc.org/transportation/t2040/t2040-pubs/final-draft-transportation-2040

Recognizing the limitations of most travel models to address strategies such as demand management and incentives, Oregon DOT developed the GreenSTEP Model to test various scenarios for reducing transportation sector GHG emissions. This tool is the basis for the Energy and Emissions Reduction Policy Analysis Tool (EERPAT) tool, which is being promoted by FHWA as a statewide GHG policy analysis tool for providing rapid analysis of many scenarios that combine effects of various policy and transportation system changes. EERPAT is an open source tool and is designed to be adapted and used by other States. EERPAT is sensitive to a variety of different policies, including carbon taxes, policies that incentivize the introduction of low carbon vehicle technology, public policies that incentivize fleet turnover, policies to increase transit capacity and ridership, policies to promote intercity rail and bus transport, policies that improve walkability and transit access, urban growth boundaries and household and business transportation demand management programs.

The impacts of these policies may overlap each other and in many cases the benefits of individual strategies may not be additive when used together. The EERPAT model accounts for this, and incorporates various secondary effects of policies. For instance, the model accounts for the rebound effect when fuel economy improvements are implemented. By re-calculating household budgets to

include fuel economy savings due to new vehicle technologies, EERPAT incorporates potential increases in demand for VMT caused by lower travel costs.

Metropolitan GHG Reduction Targets and Scenario Planning
Portland Oregon

In 2007, the State of Oregon adopted a goal to reduce all GHG emissions to 75% below 1990 levels by 2035. The State Land Conservation and Development Commission (LCDC) adopted GHG reduction targets in 2011 to help guide the State's MPOs as they conduct scenario planning which is required in the Portland and Eugene/Springfield areas, as part of the statewide effort. The other MPOs are not required to conduct scenario planning but may do so on a voluntary basis. Targets were set based on an assessment of what is possible to be accomplished at the metropolitan level. These targets call for a 17-20% reduction in transportation-related GHGs in each metropolitan area by 2035 in order for the State to meets its 2050 goal. State law (HB 2001) requires Metro and the Portland metropolitan area local governments to develop and select a preferred land use and transportation scenario that achieves the GHG emissions reduction targets. Portland Metro's Climate Smart Communities scenario planning process includes six desired regional outcomes which serve as guiding principles for the Climate Smart Communities Project. Metro's scenario planning process identified evaluation criteria that could assess scenario performance on all of the region's six desired outcomes. Climate Smart Communities Scenarios Project: Strategies Toolbox discusses the scenario planning process in detail and the various strategies researched.

www.oregonmetro.gov/index.cfm/go/by.web/id/36945

Assessing Tradeoffs and Understanding Co-benefits

A challenging part of PBPP is to consider how an agency will weigh tradeoffs among different goals areas. For example, how will GHG reductions be weighted in comparison to criteria pollutant emissions reductions? Or more broadly, how important is GHG reduction in comparison to safety or economic development? Are there strategies that generate a win-win for multiple goal areas? This balancing of goals and priorities is achieved through qualitative and quantitative analysis and most importantly through the decisions made by policy makers about relative priorities within a region.

One of the advantages of many GHG reduction strategies is that they tend to support other regional and State goals that are typically included in LRTPs. For example, transit investments support mobility, access to jobs, increasing travel choices, reducing emissions and reducing VMT and GHGs. Another example is improving rail-freight grade crossings. These investments may improve traffic flow, reduce particulate matter (PM) emissions, encourage rail freight, and reduce energy consumption and GHGs. Many of the other types of investments that State DOTs and MPOs traditionally make also can support

reducing GHGs. There are also co-benefits in that many strategies reduce multiple pollutants of concern (e.g. VOCs, NOx, CO, PM-10, PM2.5, etc.).[53] Other examples of co-benefits include:

- Increase in physical activity,
- Improvement in roadway safety,
- Reduction in household transportation costs,
- Economic development, and
- Cost savings for local agencies.

The Sacramento Area Council of Governments (SACOG) tested seven policy scenario options as part of the GHG target setting required by State law. The work was done to inform SACOG and others of the GHG reduction potential of various scenario options, each of which was focused on expanding a policy bundle. The scenarios included land use enhancements, transit enhancement, system and demand management enhancement and pricing. Two scenarios assessed the possibility of combining elements of these policy bundles.

SACOG staff have made a concerted effort to ensure that various considerations are being measured from a consistent base so that each scenario is evaluated using the same data. The decision makers do not use a scoring system, but they do look at all of the possible outcomes and assess what strategies do and do not work well together. SACOG highlights the co-benefits of its strategies as a way to convince decision makers how to get the best return on transportation investments. SACOG addresses trade-offs by creating scenarios that revolve around specific priorities so that decision makers and the public can develop their own opinion of the best scenarios. The final plan includes just one scenario that is a combination of the best elements from 3 or 4 other near-final scenarios.

See a description of SACOG Scenario Testing:
http://www.arb.ca.gov/cc/sb375/mpo/sacog/sacog.rtac.scenarios.pdf

Prioritizing Projects for Funding

Performance information can be used to prioritize projects for funding. Although project-level emissions analysis is not typically conducted in relation to performance measures, States and MPOs can use quantitative or qualitative information to assess how different projects or more likely, groups of projects, contribute to different goals. For instance, DRCOG in Denver, CO estimates emissions impacts of transit passenger facilities projects, bus service projects, new bicycle and pedestrian projects, and air quality improvement projects, and uses this information as part of a scoring matrix to prioritize projects.[54] High scores are awarded to those projects that aim to reduce the largest amount of emissions as a percentage of the regional total. The Puget Sound Regional Council in Washington State has

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[53] See FHWA, Multipollutant Emissions Benefits of Transportation Projects, While CO_2e was not investigated as part of this effort, many of the transportation emissions reduction strategies available to State DOTs and MPOs would also reduce CO_2e. https://www.fhwa.dot.gov/environment/air_quality/conformity/research/mpe_benefits/mpe01.cfm

[54] Denver Regional Council of Governments. Policy on Transportation Improvement Program (TIP) Preparation. 2010. Available at: http://www.drcog.org/agendas/DRAFT%202012-2017%20TIP%20Policy-MVIC%20Version.pdf.

discussed the concept of creating approaches, such as monetizing benefits, which allow projects to be prioritized using criteria that are relatively comparable and also allow for cost-benefit analyses. Monetizing benefits would also be useful because State officials have limited funding for transportation, and monetizing benefits could provide a mechanism to raise the priority of GHG reduction projects relative to other traditional transportation improvements that can be monetized.

Another approach is to designate specific funding for transportation climate change initiatives and prioritize funding based on estimated GHG reduction potential or cost-effectiveness. The MTC in the San Francisco Bay Area has developed a Climate Initiatives Program, which specifically was designed to fund programs that reduce GHG emissions, and have other co-benefits.

Integrating greenhouse gases into planning and programming in Massachusetts - In 2008 Massachusetts passed the Global Warming Solutions Act that requires the State to set a goal for reduction and create transportation plans that are consistent with that goal. The goal has been set at a 25 percent reduction by 2020 in GHG emissions from a 1990 baseline.

Long-range planning documents, including statewide planning documents (e.g. the Strategic Plan, State Freight Plan, and MassDOT Capital Investment Plan), as well as the long-range Regional Transportation Plans from the Metropolitan Planning Organizations (MPO), must address MassDOT's three sustainability goals and plan for reducing GHG emissions over time. Similarly, the shorter-range regional and State Transportation Improvement Programs (TIPs and STIP), under which particular projects are chosen for funding in the coming four years, must be consistent with the Commonwealth's GHG reduction target. This will require that the MPOs and MassDOT balance highway system expansion projects with other projects that support smart growth development and promote public transit, walking and bicycling. In addition, the project programming mix included in the RTPs, TIPs and STIP can contribute to GHG reduction through prioritizing roadway projects that enable improved system operational efficiency, without expanding overall roadway system capacity. Currently the TIPs provide a numerical ranking for projects on several different factors, including their contribution to GHG emissions.

MassDOT and the MPOs have developed approaches for identifying the anticipated GHG emission impacts of different project types. All TIP projects have been sorted into two main categories for analysis: projects with quantified impacts and projects with assumed impacts. Projects with quantified impacts consist of capacity-adding projects from the LRTP and projects from the TIP that underwent a CMAQ spreadsheet analysis. Projects with assumed impacts include projects that would be expected to produce a minor decrease or increase in emissions and projects that would be assumed to have no CO_2 impact.

For more information see Appendix C: Greenhouse Gas Monitoring & Evaluation.
http://www.ctps.org/Drupal/data/html/plans/TIP/FFYs_2014_2017_Draft_TIP.html#appc

Since the transportation planning process is continuous, transportation plans and TIPs are updated periodically and State DOTs and MPOs routinely adjust program priorities based upon changing circumstances and resource constraints. As the new performance requirements included in MAP-21 are implemented, State DOTs and MPOs are expected to begin setting clear performance targets and using those targets to inform investment decisions in the required areas. If an MPO or State DOT chooses to adopt GHG reduction targets as part of their PBPP and as a means to support the environmental sustainability goal under MAP-21, then GHG reductions can be considered as an additional return on potential project investments.

8. Monitoring, Evaluating, and Reporting on GHG Performance

The goal of PBPP is to use performance data to inform and influence decisionmaking, especially with respect to the allocation of scarce resources. *Monitoring system performance* and *evaluating programs and projects* are the two key activities involved in the feedback loop that is part of a PBPP process. In the context of PBPP, it is important to distinguish between monitoring system-level performance and evaluating performance of investments, given the limited control that transportation agencies have over some outcomes. Reporting is the process through which performance is conveyed to various constituencies including policy- and decision-makers and the general public.

Monitoring GHG Emissions Performance

Monitoring provides information on actual conditions on a periodic basis and allows for periodic assessment of whether targets have been or are likely to be attained. Data collected informs transportation decision-makers about progress made toward goals and targets. Monitoring plans address issues such as what is being tracked, what data need to be collected, who will collect it, how it will be collected, where it will be stored, and how it will be reported back to the end user.

For GHG emissions, one key challenge is that monitoring requires some form of calculation or modeling since emissions are not directly “measured.” If using fuel consumption as a more direct measure to calculate GHG emissions, it is important to recognize that fuel consumption data may not align well with VMT data used for forecasting and analysis within the planning process. However, on-going development of GHG inventories will provide a useful context both for overall State and regional performance, changes in the contributions of different sources to emissions, and for understanding factors that have influenced those changes.

Monitoring system performance is an ongoing process. For certain metrics, such as those related to safety and congestion, data may be compiled annually, quarterly, or even monthly or more often. For GHG emissions, annual reporting, or reporting in relation to each LRTP update, is likely the most appropriate reporting cycle.

Evaluating Performance

Evaluating performance is the process of taking information and drawing inferences as to why performance on various measures changed; in other words, interpreting the results. It goes a step beyond monitoring and tracking and attempts to understand whether implemented strategies have been effective in contributing toward positive performance outcomes. Two types of evaluation may be conducted:

- **System-level performance evaluation** - Regional analysis to assess the extent to which transportation investments and policies have contributed toward a target;
- **Project-level or program-level analysis** to assess impacts of specific strategies.

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System-level Evaluation

Identifying the system-wide effects of transportation agency programs and activities is difficult, and requires modeling a "business as usual" or counterfactual scenario to see what GHG emissions would have been absent the implementation of GHG reduction strategies. System level evaluation incorporates the impacts of many different specific projects and programs. Ideally system level performance evaluation should focus on the outcomes achieved by the transportation system. For instance, the Central Lane MPO in Oregon uses internal VMT/capita, average trip length and % of person trips under one mile to evaluate the sustainability of its transport system performance and its long range plan. Mode shares for walking, bike, transit, or shared ride auto are also used. System characteristics such as bikeway miles, transit service hours per capita and percent of households within ¼ mile of a transit stop are included in their evaluation process. These measures are only indirect measures of GHG emissions, since changes in technology have reduced GHG emissions per VMT.

Some agencies have assessed the air quality and GHG emissions impacts of reductions in congestion on a system-wide basis using the MOVES model. More direct measures of transportation GHG emissions include total transportation GHG emissions for a region or transportation GHG emission per capita. These measures are less directly linked to specific transportation policies. System level evaluation can be more challenging since there are so many different policy, technology, and economic factors that affect GHG emissions at the system level, and transportation agencies may have only indirect influence over many of these factors. More commonly, evaluation focuses on a specific set of strategies or programs.

Project or Program-level Analysis

A State DOT or MPO can fund studies to measure the effectiveness of particular strategies or projects by examining conditions before and after, or with and without, a strategy of interest. For instance, a study could be conducted to quantify VMT reductions or mode shifts of a transportation demand management (TDM) program, to quantify the speed improvements associated with traffic flow improvement projects, to examine the reduction in vehicle delay associated with operational strategies, or other similar types of impacts. Projects and programs can be evaluated in terms of their emission reduction cost effectiveness, co-benefits, and on other criteria. The specific methods for determining impacts will vary from project to project; however, a common analytical framework can be applied to ensure an "apples to apples" comparison. This section describes a basic framework for evaluation and some of the concepts and components that should be considered. These include:

- Transportation Impacts
- Emissions Impacts
- Costs and Cost-Effectiveness
- Co-Benefits
- Lessons Learned

Transportation Impacts

The two most common types of impacts for projects or programs that reduce GHG emissions are reduced VMT and reduced emissions per mile (from cleaner vehicles, or eco driving for example). Some projects may not fit neatly in either of these two categories and may require tailored approaches.

VMT Reduction Projects / Programs - The methods for determining VMT reduction will vary by project. In general, these projects are more difficult to evaluate than clean vehicle projects because they require measurement of behavior change.

A preferred approach is to measure travel behavior before and after the project or program implementation. This can be done through a survey – by telephone, by mail, by internet, online, and/or in person. The appropriate data collection methodology (or combination of methods) will depend on the nature of each project. In general, the respondent is asked about their travel behavior (trip frequency, mode, trip distance, etc.) before the project occurs, and then is asked similar questions after the project. For some projects like bicycle or pedestrian projects, counts of pedestrian and bicycle activity before and after the project may be sufficient to estimate changes in vehicle trips and therefore VMT.

A major challenge with the before and after survey approach is that it is resource intensive. Another challenge is that, in some cases, the target population (e.g., users of a new bikesharing station) will not be known until the project has been implemented, so conducting a "before project" survey is not possible.

Evaluation of some projects may require the use of a control group – a similar population that is not subject to the project activities and is surveyed and monitored for behavior change like the target population. An alternative approach is to survey participants to ask how they traveled prior to the new project/service, or how they would have traveled in the absence the project/service. This "retrospective surveying" has been the approach taken in several evaluations of bikesharing programs, for example. Accuracy may be a challenge with this approach, particularly if respondents are asked to speculate about hypothetical travel or recall travel that occurred more than several weeks in the past.

A challenge with either approach is a bias toward what is perceived as the socially desirable answer. Some respondents will overstate their reduction in automobile use, for example, knowing that it is a goal of the project and considered more acceptable by society. This potential source of bias is a chief concern – and it may dictate the use of split-sample and/or more complicated questionnaires in order to minimize or mitigate its impact.

An additional challenge when sampling to estimate the impacts of a project or program is that sample size will determine, to some degree, the ability of the research to measure statistically reliable changes in behavior. The smaller the program impacts, all other things being equal, the larger the sample needed to measure the impacts. For each project, therefore, the appropriate sample size needed to evaluate the program will depend, in part, on the expected magnitude of impact needed for the project to be deemed "successful".

When determining VMT impacts, it is important to account for all vehicle activity affected by a project/program. In some cases, a reduction in automobile VMT may be offset by an increase other vehicle activity. For example, evaluation of a new shuttle service should account for the travel and emission of the shuttle itself. A bikesharing program may generate new VMT from the vehicles required to redistribute bicycles among stations.

Reduced Emissions per Mile (Clean Vehicles, etc.) - Some project evaluations will focus on the introduction of cleaner vehicles. In general, these types of projects require the collection of data on vehicle activity (VMT) as well as the fuel source used. For electric vehicles, charging information (charge duration, time of day, metered energy use) would be collected. It may also be important to account for the differences in emissions per kilowatt hour for base load and peak power usage for vehicle charging. In general, it may be important to account for life-cycle emissions for different types of fuels, including conventional fuels. For instance, fugitive emissions from natural gas vehicles or pipeline transmission may add significantly to the tailpipe emissions of natural gas vehicles. It is typical to assume that a low emission vehicle project would not change the demand for travel, unless project data suggests otherwise.

Emissions Impacts

Impacts on GHG emissions can be calculated by applying emissions factors to estimates of vehicle travel. The factors used to calculate GHG emissions impacts should be consistent across evaluations while at the same time reflecting the specific nature of the transportation activity changes. As discussed earlier, the MOVES model is one national source for emissions factors. It may be important to develop factors specific to a project in some cases. For example, if a project is replacing travel by older vehicles, emission factors could be created that reflect only vehicles of the relevant model years. If a project is eliminating only highway travel, emission factors could be created that reflect highway speeds.

Costs and Cost-Effectiveness

Project or program evaluations should consider evaluating the cost-effectiveness of program expenditures. Project cost-effectiveness can be determined by dividing the project costs by the emission reduction. Project costs can include multiple components. For example, costs could include only the regional agencies public expenditure, agency expenditures plus other State and local government costs, all government and private sector costs, or all costs from a societal perspective. Ultimately, the appropriate cost definition depends on how the cost effectiveness metric will be used.

For calculations of cost effectiveness, consider evaluating cost in two ways:

- Total public cost – Sum the public expenditures (including Federal, State or local government match). This measure of cost effectiveness allows for “apples to apples” comparison across projects and identifies what are the most cost effective ways for public agencies (as a whole) to reduce GHGs.
- Total cost – Sum public expenditures, in-kind costs used as a local match, and private funding.

Costs to users, such as a reduction in automobile ownership costs, can be assessed as a co-benefit.

A key concept in cost-effectiveness analysis is the "lifetime" of the emission reduction. For projects that provide an on-going service, like support for a ridematching program or a new shuttle service, it can be assumed that the emissions benefits last only as long as the program is in place. Thus, one year of funding buys one year of emission reduction. But other types of projects may have emissions benefits that remain after the grant funds have been expended. This is true of most infrastructure projects, for example.

There are a variety of approaches for addressing this issue in a cost-effectiveness calculation. In general, they seek to determine the average annual cost over the lifetime of the emission reduction. For instance the methodology typically used by the California Air Resources Board (CARB) for determining emission reduction cost-effectiveness[55] involves calculating an "annualized capital cost", which is the amortization of the one-time incentive grant amount for the life of the project. In effect, the annualized capital cost is the expected yearly return if the total capital cost were invested over the lifetime of the project.

It is important to select an appropriate discount rate for the cost-effectiveness calculations. Some State agencies use a 4% discount rate, which is intended to reflect the prevailing earning potential for State funds that could reasonably be expected by investing in various financial instruments. A lower rate may be needed to reflect current investment conditions. In San Francisco, MTC has used 2.2% discount rate for some analyses.

Some projects may also have annual operations and maintenance (O&M) costs in additional to an initial capital investment. If so, the average annual operating cost can be added to the annual capital cost.

While cost-effectiveness calculations can often help to prioritize GHG emission-reducing projects for funding, it is important to note that co-benefits, which are not typically included in cost-effectiveness calculations, should supplement the dialogue. It is difficult to express through a cost-effectiveness calculation the more holistic benefits of emission reductions, and so it is recommended that cost-effectiveness serve as only one piece of the discussion about the need for emission-reducing program investments. A more complete discussion of co-benefits is given below.

Co-Benefits

Many GHG mitigation projects and programs have associated co-benefits in addition to GHG emission reduction. Such co-benefits might include congestion reduction, increased walkability, enhanced travel options, and reduced criteria pollutants, among others. Identifying these co-benefits, and, to the extent possible, assessing them in a quantitative or qualitative manner, can contribute significantly dialogue

[55] See for example, Air Resources Board, The Carl Moyer Program Guidelines, 2008, available at: http://www.arb.ca.gov/msprog/moyer/guidelines/current.htm

about GHG emission reduction strategies. The specific co-benefits and methods for assessing them will differ from project to project.

In addition to identifying and perhaps quantifying the co-benefits of new GHG reduction strategies, it is important to highlight GHG emissions reductions as a co-benefit on many existing transportation projects and programs. As an example, policies or activities in place to reduce congestion or energy use have the added benefit of reducing GHG emissions. Doing so can help express to decision-makers the idea that GHG emissions reductions strategies are not new and not altogether unfamiliar.

Lessons Learned

Among the key objectives of an evaluation is to learn from the individual projects and programs that are being implemented in the field. One approach to creating lessons learned is to use a summary assessment approach to identify the key lessons learned from each project and program, and assess how replicable it is to expand the projects/programs on a much broader scale.

The specific questions and approach for determining lessons learned will vary from project to project. Some projects have no precedent in a region or State and an evaluation can provide a wealth of new lessons learned concerning every aspect of the project. Other project types may have a history of implementation and past evaluation. An evaluation in these cases will focus on understanding what changes could make such projects more effective in the future. In general, an evaluation of lessons learned could consider the following issues and questions:

***Effectiveness* -** What are the project's keys to success? How did measured project impacts compare to forecasted impacts? What might be the reason for any differences? What changes would have made the project more effective? What changes would increase its adoption?

***Replication* -** What factors need to be in place for the project to be successfully replicated? What is the extent of potential replication? If the project were replicated elsewhere, would we expect the cost effectiveness to change?

***Scalability* -** To what extent could the project be increased in scale (e.g., to larger target populations or larger geographic areas)? If the project were scaled up significantly, would we expect the cost effectiveness to change?

***Duration of Impacts* -** Will benefits persist once the project has ended? How long can they be expected to persist? What changes would help to maximize the duration of benefits?

***Role of Technology* -** To what extent did the project contribute to deployment or adoption of new technologies? How will new and emerging technologies affect the project? Could new technologies make similar projects more effective in the future, or irrelevant or unnecessary in the future?

One example of a program evaluation is the Metropolitan Transportation Commission's (MTC) evaluation of their Climate Initiatives Program. In December 2009, MTC, the transportation planning commission for the nine-county San Francisco Bay Area, programmed $80 million over a three-year period for a number of initiatives meant to reduce GHG emissions associated with transportation. These initiatives included:

- The purchase of electric vehicles and charging stations, electrifying car sharing, a demonstration of battery electric vehicles for San Francisco neighborhood taxis and deploying bay area electric vehicle infrastructure;
- Demonstrating dynamic ridesharing technology in three counties, developing bike sharing programs, parking pricing pilot programs and various other TDM programs;
- Development of school transportation "green teams", funding for a bike repair and encouragement vehicle and other school transportation programs; and
- The Green My Ride Program, a TDM program that merges municipal fleet operations, electric vehicles, and carsharing into a Guaranteed Ride Home for employees.

MTC initiated an evaluation program to measure the costs and benefits of these programs. The focus of the effort was to determine the effectiveness of these programs and projects at reducing GHG emissions. Survey data was used to evaluate some of these projects, but other qualitative and quantitative methodologies were also used. The evaluation included the creation of a baseline scenario and an estimation of transportation impacts, emissions impacts, costs and co-benefits, and a description of lessons learned.

Another example of a program evaluation includes efforts by the National Capital Region Transportation Planning Board (TPB) at the Metropolitan Washington Council of Governments in the Washington, DC region to quantify the effectiveness of its Commuter Connections TDM program. TPB conducts a regional State of the Commute Survey, along with additional surveys such as a Guaranteed Ride Home Program survey and tracking of participation rates in programs, in order to analyze the vehicle travel reductions and air quality improvements associated with the program.[56]

Another approach is for the State DOT or MPO to develop guidance for evaluating strategies, and require local project sponsors to conduct evaluations of their projects and programs. Guidance can be provided on when an assessment should be done, what measures should be used, how data should be gathered, what methods should be used to analyze the data, and other aspects of evaluation studies. This approach is appropriate where partner agencies are responsible for implementation of strategies.

[56] See the most recent State of the Commute Survey Report from 2010 available online at http://www.mwcog.org/store/item.asp?PUBLICATION_ID=415.

Reporting and Communicating Performance

The way in which information about system performance in comparison to targets is communicated to policymakers and the public can have significant implications for agency and program support. Effective reporting tells a story and explains the societal trends (e.g., land use changes, demographic changes) and other factors that may be influencing results. Transportation organizations communicate performance results to a number of different audiences. First, the organizations collect and analyze data and circulate performance results internally. In addition, they report results both to the general public and to leaders and policymakers. In the case of the public and policymakers, simple graphics, visuals, and dashboards can be useful for communicating information in ways that the public can understand. Moreover, it is important to not just present information, but also to provide context for trends to tell a story about why performance has changed. To the extent possible, visuals should show past performance to provide context for current results. In addition, where appropriate, the organization can also provide counterfactual information, for example, about performance that would have been expected without the investments that were made. This can be particularly relevant for GHG emissions, given the many factors affecting GHG emissions that are beyond the control of transportation agencies.

Additionally, effective communication regarding GHGs could serve as a catalyst for interagency partnerships to reduce surface transportation GHG emissions. State DOTs, MPOs, local governments, State legislatures, the private sector, developers, the auto industry, and other stakeholders play an important role in reducing GHG emissions based on their roles in land use decisionmaking, road use pricing (including consideration of strategies such as VMT-fees, pay-as-you-drive insurance, and fuel taxes), speeds limits and enforcement, and creating incentives for purchasing fuel efficient vehicles, among other strategies. Consequently, communicating information about GHGs could help to engage discussions among these partners.

Caltrans Regional Progress Report

California DOT's Regional Progress Report is part of an ongoing State effort to understand the intersection between land use, mobility, housing, infrastructure and natural resources preservation as they relate to a region's economic vitality, quality of life, and environmental quality. In 2007, the first California Regional Progress Report introduced regional quality of life indicators based on Regional Blueprint Planning goals. The 2010 Report builds on the foundation laid in 2007, but expands upon it to help meet the State's need for coordinated sustainability planning and assessment.

The Report is available at: http://www.dot.ca.gov/hq/tpp/offices/orip/Collaborative%20Planning/California_Regional_Progress_Report.html

9. Relevant Resources

This document builds on a wide range of resources that focus on specific issues in relation to this document. The references below may be helpful for further information.

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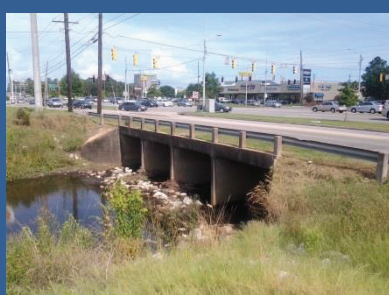
U.S. Department of Transportation
Federal Highway Administration

1200 New Jersey Avenue SE
Washington, DC 20590
www.fhwa.dot.gov/planning

Publication No.: FHWA-HEP-14-020

Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: The Gulf Coast Study, Phase 2

Task 3.2: Engineering Assessments of Climate Change Impacts and Adaptation Measures



U.S. Department of Transportation
Gulf Coast Study, Phase 2

August 2014
FHWA-HEP-15-004

Impacts of Climate Change and Variability on
Transportation Systems and Infrastructure

The Gulf Coast Study, Phase 2

Engineering Analysis and Assessment

Final Report, Task 3.2

Prepared for:

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With contributions from

South Coast Engineers

Date: **August 2014**

Contract No.: **GS-10F-0124J**

Report No.: **FHWA-HEP-15-004**

Acknowledgements

The authors gratefully acknowledge the assistance from the following:

- The Mobile Metropolitan Planning Organization's Climate Change Work Group
- The U.S. Department of Transportation's Gulf Coast Phase 2 Technical Advisory Committee
- *Local Experts on Highways:* Kevin Harrison and Tom Piper of the South Alabama Regional Planning Commission; Lee Reach, Don Powell, David Ramsey of the Alabama Department of Transportation; Ricky Mitchell and Tina Sanchez, Mobile County; Nick Amberger of the City of Mobile
- *Local Experts on Ports*: Jerald Kichler

We also gratefully acknowledge the time and effort provided by the peer reviewers of this report (in alphabetical order): Eric Brown, Federal Highway Administration (FHWA); Gary Carr, Federal Railroad Administration; Andrea Hendrickson, Minnesota Department of Transportation; Casey Kramer, Washington State Department of Transportation; Jeffrey Knaub, Maryland State Highway Administration (MDSHA); Khalid Mohammed, FHWA; Cynthia Nurmi, FHWA; Karuna Pujara, MDSHA; and Laurel Radow, FHWA.

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1. Executive Summary

1.1 Background and Purpose

Facility managers, transportation leaders, and elected officials are increasingly concerned about the resilience of transportation infrastructure to a range of threats, including the threats posed by climate change and extreme weather. However, the information and tools necessary to understand, evaluate, and rank vulnerabilities remain scarce. This is particularly true as it relates to specific facilities and assets; even more scarce is information and data regarding adaptation (i.e., risk mitigation) measures, their efficacy in reducing risks, and the returns on investment that might be expected if adaptation strategies are adopted. While some resources exist for evaluating transportation system vulnerability at a broad level, there is little guidance on how to do so at the facility-level. Likewise, general information on adaptation options is known, but there have been few asset-level analyses evaluating the potential effectiveness of those options.

Acknowledging the importance of establishing systematic, transferrable approaches for assessing and addressing vulnerability to climate- and weather-related risks, the U.S. Department of Transportation's (USDOT) Center for Climate Change and Environmental Forecasting commissioned a comprehensive, multiphase study of climate change impacts on transportation in the Central Gulf Coast region. This study, formally known as *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study* (hereafter, "the Gulf Coast Study").[1] Phase 1 (completed in 2008) examined the impacts of climate change on transportation infrastructure at a regional scale. Phase 2 (nearing completion) provides a more detailed assessment of the vulnerability of the most critical components of the transportation system in Mobile, Alabama to weather events and long-term changes in climate.

This report discusses a series of engineering assessments on specific transportation facilities in Mobile that evaluated whether those facilities might be vulnerable to projected changes in climate, and what specific adaptation measures could be effective in mitigating those vulnerabilities. The purpose of the engineering assessments was twofold:

(1) Develop and test a detailed climate impact assessment process (*The Process*) that both evaluates the climate vulnerabilities of specific transportation assets, and evaluates possible adaptation strategies that could be implemented. The methodologies developed for these assessments could be applied to similar facilities elsewhere. This report represents one of the few resources available to transportation practitioners that include engineering methodologies for evaluating climate change vulnerabilities and adaptation measures at the facility level.

[1] For background information on the Gulf Coast Study, please see Section 2.

(2) Explain and document Mobile-specific findings for each facility-climate stressor pair, including any findings that may apply more generally to engineering design practices, operations and maintenance practices, or other lessons learned.

1.2 Overview of the General Process for Transportation Facility Adaptation Assessments

Climate and weather have always played an important role in the planning and design of transportation infrastructure. Facilities of all types are planned to avoid high hazard areas whenever possible, bridges must be designed to accommodate floods, pavement must be able to tolerate extremes in temperature, etc. However, the prospect of long-term changes in climate and more extreme weather presents a fundamental challenge to transportation professionals. Consideration of long-term climate change threats will increasingly be required when planning, designing, and in some cases, operating/maintaining new infrastructure. Due to the lack of standard approaches or models for attempting this, this project developed a *General Process for Transportation Facility Adaptation Assessments* (the *Process*).

The *Process* provides an 11-step framework for determining the vulnerabilities of an individual transportation facility to climate change, developing adaptation options to mitigate risks of anticipated changes, and selecting a course of action. The 11 steps are:

1. **Describe the Site Context** – Describe location-specific details, such as surrounding land uses, population, economic activities; performance characteristics; proximal historic or sensitive environmental resources; long-term transportation and land use plans, and whether they account for climate change impacts; function(s) the facility serves or will serve within the broader transportation network.
2. **Describe the Existing / Proposed Facility** – Describe facility-specific details, such as location, functional purpose, design type, dimensions, elevations, design life, age, condition, and design criteria.
3. **Identify Climate Stressors that May Impact Infrastructure Components** – Identify climate-related variables that are typically considered in planning and design of the type of facility being investigated (e.g., precipitation, temperature, sea level, storms).
4. **Decide on Climate Scenarios and Determine the Magnitude of Changes** – Describe climate model projections that are used to determine whether and how much each of the variables of concern may change in the future.
5. **Assess Performance of the Existing / Proposed Facility** – Assess whether the existing/proposed facility is performing as expected/modeled under current climate data and design assumptions and whether it will continue to do so under each of the possible future climate scenarios selected in Step 4.
6. **Identify Adaptation Option(s)** – Identify potential planning, design, and maintenance / operations options that could be used to address climate risks to the facility.

7. **Assess Performance of the Adaptation Option(s)** – Assess the performance of each adaptation option under each potential climate change scenario selected in Step 4. This analysis is similar to Step 5 except that it is performed on the adaptation options instead of the existing facility or, in the case of new facilities, the standard design.
8. **Conduct an Economic Analysis** – Evaluate how the benefits of undertaking a given adaptation option, defined as the costs avoided with adaptation, compare to its incremental costs under each of the possible future scenarios developed in Step 4.
9. **Evaluate Additional Decision-Making Considerations** – Identify and evaluate other (non-engineering, non-economic) factors that should be considered before a final decision is reached.
10. **Select a Course of Action** – Consider both economic and non-economic factors, weighing all the information presented, and select a course of action.
11. **Plan and Conduct Ongoing Activities –** Identify, plan for, and conduct ongoing activities (such as monitoring), using tools such as facility management plans.

The Process was developed to be general enough to be applied to multiple transportation modes and asset types. It can also be used both for existing facilities, where adaptive retrofits might be considered, and for proposed new facilities where adaptation measures can be incorporated into the design.

This *Process* was employed throughout each of the case studies discussed in this report. For each case study, the *Process* was used to evaluate vulnerability of a specific asset to a certain projected climate stressor (such as increased temperatures, sea level rise, storm surge), and also to evaluate potential adaptation measures.

The climate data used in the case studies was developed during previous tasks of this project. See the Task 2 and Task 3.1 reports at www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task2/sensitivity_report/ and www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task3 for more information on how the climate projection information was developed.

1.3 Overview of Case Studies Selected to Demonstrate the *Process*

Ten case studies were conducted to demonstrate the application of the *Process* to a range of design problems at 10 specific facilities in Mobile, Alabama. In addition, operations and maintenance (O&M) opportunities for adaptation were examined in a final case study. These case studies illustrate how engineering design processes may be augmented to incorporate climate change and extreme weather considerations. Table 1 lists the climate stressors and asset types chosen for study and the specific facilities that were investigated. Figure 1 shows the location of these facilities. Since the case studies are intended to demonstrate the application of the *Process*, each case study is structured using the 11 steps of that *Process*. Due to the nature of

this project as a broad study across many facilities (rather than an in-depth study of a single project), none of the case studies represent a full application of every step in the *Process*.[2]

This report showcases engineering assessments across a range of transportation asset types and climate change stressors. The facilities chosen for the engineering assessment were not necessarily the most vulnerable assets; instead, they represent a broad range of facility types and climate stressors in hopes that methods developed here might be instructive, not only for Mobile but for transportation agencies nationwide.[3]

[2] There is variation in the degree to which each step was completed across case studies, due to resource and data constraints, and applicability of each step. For example, for assets not likely vulnerable to the climate stressor analyzed, Step 7 (Assess Performance of Adaptation Options) was not completed in detail. Additionally, there were not sufficient resources to complete the Step 8 (Economic Analysis) for all case studies, so the first case study is the only one that includes a detailed economic analysis; this serves as a possible methodology for analyzing economics of others as well.

[3] Note that neither the *Process* nor the facility-specific findings are intended to change specific design methodologies for assets or to serve as an alternative approach for designing projects. Findings are illustrative and represent a first attempt to systematize an approach for incorporation of climate and weather risks into engineering analyses using facilities in Mobile as case studies.

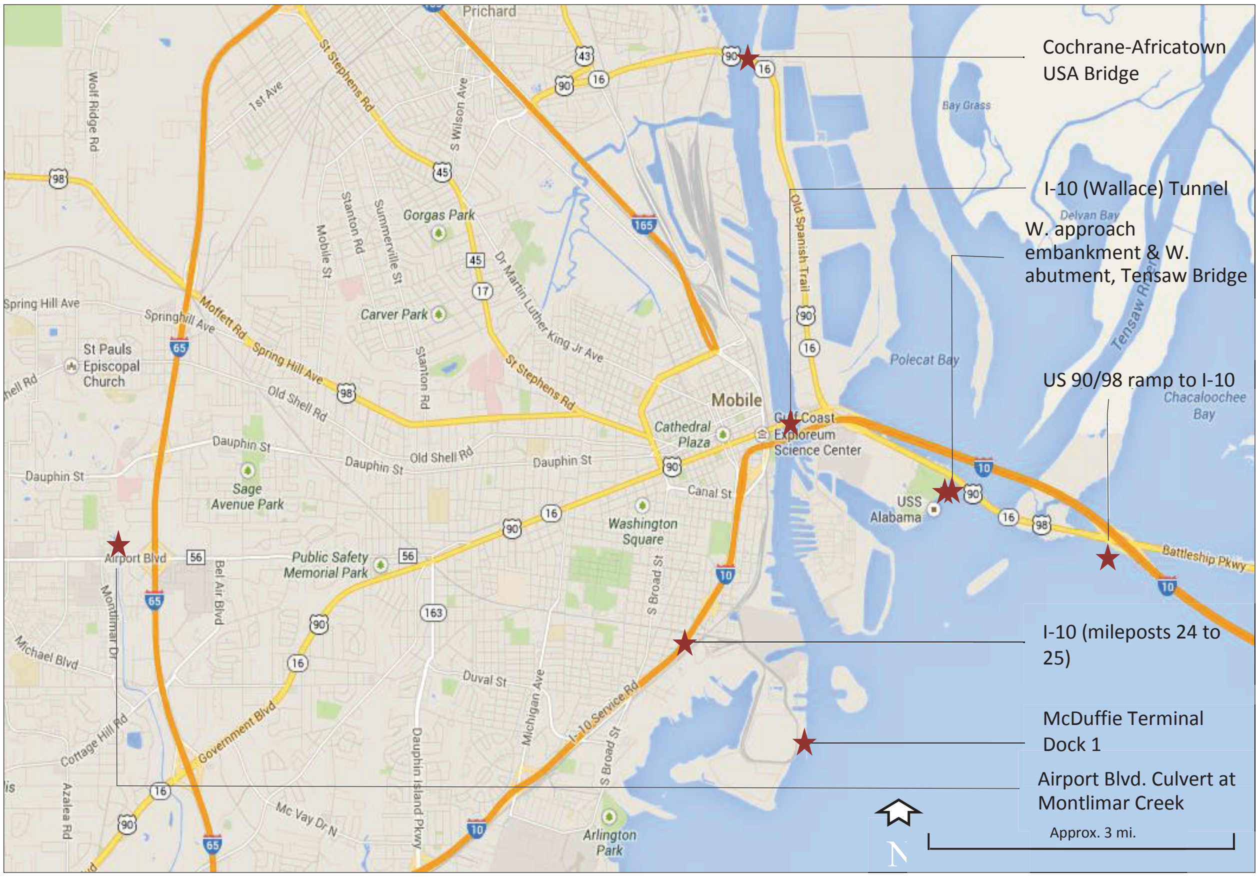
In presenting these illustrative examples, the authors are not suggesting that transportation agencies would apply such detailed analyses to all assets under their purview. Rather, transportation agencies may wish to conduct detailed analyses for specific assets considered to be particularly critical, vulnerable, expensive to replace, due for an upgrade/replacement, etc.

Table 1: Listing of Case Studies by Climate Stressor, Facility Type, and Damage Mechanism

Report Section	Climate Stressor	Asset Type	Damage Mechanism	Asset Location	**Indicator-Based Vulnerability***
4.4.1	Increased precipitation	Culvert	Flooding	Airport Boulevard culvert at Montlimar Creek	Low
4.4.2	Sea level rise	Navigable waterway bridge	Clearance for navigation	Cochrane-Africatown USA Bridge	Medium
4.4.3	Sea level rise	Bridge approach embankment	Slope erosion	West approach embankment of the US 90/98 Tensaw-Spanish River Bridge	High
4.4.4	Higher storm surge	Bridge abutment	Abutment scour	West abutment of the US 90/98 Tensaw-Spanish River Bridge	Medium
4.4.5	Higher storm surge	Bridge segment	Wave forces, bridge pier scour	US 90/98 ramp to I-10 eastbound at Exit 30	High
4.4.6	Higher storm surge	Road alignment	Overtopping / slope erosion	I-10 (mileposts 24 and 25)	Low
4.4.7	Higher storm surge	Coastal tunnel	Flooding	I-10 (Wallace) Tunnel	Medium
4.4.8	Higher storm surge	Shipping pier	Waves	McDuffie Coal Terminal, Dock 1	Low
4.4.9	Temperature changes	Roadway pavement	Rutting, concrete crackings	Generic location	Low
4.4.10	Temperature changes	Continuously welded rail	Buckling, pull-aparts	Generic location	Medium
4.4.11	Precipitation, wind, temperature, sea level rise, hurricanes	Operations and maintenance activities for various facilities	Varies based on climate stressor	Alabama Department of Transportation, City of Mobile, and Mobile County operations and maintenance practices	High

* An asset's estimated vulnerability was calculated previously in this project, as detailed in the report *Task 3.1: Screening for Vulnerability*. The vulnerability designations developed within the *Screening for Vulnerability* report provide initial estimates of an asset's vulnerability to a particular climate stressors based on a series of vulnerability "indicators" applied broadly across the transportation system. However, in this *Task 3.2 Engineering Analysis and Assessment* report, the more refined engineering analyses performed may result in different determinations as to an asset's actual vulnerability.

Figure 1: Case Study Locations[4]



1.4 Key Lessons Learned

The analyses conducted through the case studies yielded some important lessons learned regarding the applicability of the *Process* and developing input values for engineering designs.

1.4.1 Applicability of a General Process for Transportation Facility Adaptation Assessments

One of the important lessons learned from the engineering case studies is that the 11-step *Process* can be successfully applied across different types of assets and for a range of climate-change stressors. In fact, the *Process* was specifically developed to generate consistency among various engineering disciplines working on this project. The *Process* can therefore serve as an organizing framework for how engineering design can be undertaken considering the uncertainties associated with possible future environmental conditions.

Another lesson learned is that there is an important need for additional guidance on how engineering design can be undertaken given uncertainty about future conditions. As mentioned

[4] Source of base map: Google Maps (as modified)

above, there is very little engineering guidance for handling climate change-related uncertainty in the engineering design process. In developing many of the engineering case studies, considerable discussion and debate occurred among the designers representing different engineering sub-disciplines (including structural, hydraulic, geotechnical, and pavement) on the most appropriate approach for analyzing a particular asset given expected future loads and stresses. Engineering practice—and indeed engineering culture—is focused on research and statistical analyses of historical events (rainfall, extreme heat, etc.); these data provide the required input variables used in decision-making. The uncertainty associated with future input variables that are derived from climate model projections drives the need for new approaches to develop those input variables and consider their effects when making planning, design, and operations/maintenance decisions.

1.4.2 Developing General Input Values for Engineering Designs

A design process that reflects projected changes in climatic conditions has to account for possible changes in the input values of the design variables beyond simply relying on historical data. This is a significant shift from standard engineering design practice, and the case studies demonstrated example methodologies for doing so.

Engineering designs for transportation facilities rely on a determination of the stresses and loads that facility components will likely face. Identification and determination of the stresses and loads is, thus, critical to selecting designs that will provide durable and stable asset performance. The engineering profession has developed design procedures and methods that are based on years of experience and documentation of the relationships between load/stress input variables and the resulting design characteristics. Input variables used in these equations are taken from historical data. Future climatic conditions may result in changes to these variables that are not simply an extension of past trends. Thus, a design process that reflects projected changes in climatic conditions in the future would have to account for possible changes in the input values of the design variables beyond simply relying on historical data; this is not unlike designing structures to withstand seismic risks.

Appropriate Scale of Input Data

The engineering case studies illustrated the need to provide input data at a scale necessary for design purposes. This has been a challenge noted for many years and an identified gap in the application of climate scenario data in engineering design. For example, climate information is often presented in terms of ranges, or average changes over longer periods (seasons, years, decades), but engineering design often requires information on return periods (such as the 25-year event), short-term extremes (such as maximum temperature and precipitation experienced over a short timeframe), and for short timeframes such as daily or hourly events. This study developed data at the temporal and spatial scale needed to conduct engineering design at the project level. Such data were derived from the best climate modeling results available for the

region, as well as from assumptions on the best approaches for providing that data that could be used in engineering design.

The Importance of Using a Range of Climate Input Data

It is important for a robust design process that a range of climate projection data be considered, simply to make sure that even the lower estimates do not require corrective design action, and that a reference alternative is presented for the scenario analyses of the higher stresses on the assets. Additionally, in some cases the lower scenario was actually found to be more damaging than the higher scenario.

In this and most similar studies, the analysis of future climate conditions was predicated on the emission scenarios offered by the Intergovernmental Panel on Climate Change (IPCC). The IPCC offers a range of emission scenarios that are then used as inputs to multiple global climate models. Importantly, the IPCC states that each of the emissions scenarios are equally likely to occur;[5] thus, while not providing a different conclusion on any one trajectory of future climate, the climate projections derived from those scenarios are useful in providing a range of outputs that can be considered as a sensitivity test in the planning and design of transportation facilities. A range of variables has been developed that can be used and parameterized in design decisions; some data may be found to have no bearing on design while other data may have wide-ranging consequences. The case studies demonstrate that the values of the design variable inputs can have strong influences on expected stresses and loads on transportation assets, as well as on appropriate adaptation response.

Earlier tasks of this study included development of climate information (see the Task 2 reports) from which climate narratives[6] were developed (see the Task 3.1 report).[7] "Warmer" and "Hotter" narratives were developed to describe ranges of temperature values, and "Wetter" and "Drier" narratives of precipitation projections were developed for the Mobile study region for use in the engineering case studies. These narratives provided the range of climate projection data used in this study for temperature and precipitation. Task 2 and Task 3.1 also developed climate narratives for sea level and storm surge, which provided the range for those climate stressors used in the case study analyses.

The scenario approach produces a range of values for the input design variables. Depending on the environmental stressors being considered, many of the engineering case studies showed that the scenarios defined by the lower ranges of design input values had either little or no impact on the current design of the asset, or that the impacts could lead to some corrective design action. For those with no impact, the original design of the asset provided enough strength and durability

[5] IPCC, 2007
[6] Note that the term "narratives" was used in place of the term "scenario" to avoid confusion with the IPCC Special Report on Emission Scenarios; the narratives function like scenarios, as described in the Task 2 report.
[7] USDOT, 2012; USDOT, 2014

to withstand the forces that were likely to be placed on the asset assuming climate change-induced design values. In other cases, such as with storm surge, the assets were found to be vulnerable for all scenarios. In fact, with storm surge, in some cases the lower scenario was actually found to be *more* impactful than the higher scenario. This lends further credence to the importance of including lower end scenarios in an adaptation assessment.

Addressing the Design Storms vs. Modeled Future Storms

Rooting future scenarios in the experience of a single historical weather event and then altering characteristics to reflect possible future permutations, has the benefit of providing very relatable results to local stakeholders, especially if a severe storm event occurred recently. However, this approach does not allow for the calculation of a return period, which presents a challenge when comparing future asset performance against a design standard rooted in return periods (e.g., no overtopping is allowed up to the 100-year storm).

Engineering practice is based on the premise of "acceptable risk"; acceptable risk is addressed in design standards that hinge on the recurrence probability of storm events (e.g., a bridge designed to pass the 100-year storm with a 1% annual chance of occurrence). Selection of design storms or return period storms are indicative of an agency's risk tolerance and reflect a trade-off between the upfront cost of providing additional protection and the expected remedial cost in case of such an event occurring. Understanding performance relative to a return period storm is important to established engineering practice.

Scenarios marrying historical and future information were particularly important to local stakeholders in the context of developing sea level rise and storm surge projections. In the Gulf Coast Project, different sea level rise scenarios were combined with base and modified Hurricane Katrina storm surge scenarios. Modeling efforts to develop a series of storm surge scenarios enabled the consideration of increased wind intensity and modified storm tracks layered on top of historical data. This approach is novel in engineering design because "design storms" are generally defined by historical record. While these future scenarios were not analyzed for the purpose of establishing future return periods, they served as the basis for scenario-based engineering analyses. There is a need for additional research and dialogue to identify and refine approaches to considering future storm surge scenarios and the effects of climate change on the way engineering design inputs are established.

1.5 Facility-Specific Findings

The case studies yielded important findings about the vulnerabilities and adaptation options for the specific assets analyzed. The following table provides an overview of findings for each case study as well as a section reference so readers can readily find the full case study write-up. Short summaries of each case study are presented in the Lessons Learned section (Section 5).

Table 2: Case Study Locations

Case Study Name	Facility	Was it Vulnerable?	What Options are Viable?	Take-Away
Culvert Exposure to Changing Precipitation Patterns	Airport Boulevard Culvert over Montlimar Creek	The culvert is adequate for current conditions Runoff overtops roadway under projected conditions	Increasing the number of culvert cells Increasing the number and size of culvert cells Regional Drainage Area Management	Using 24-hour duration precipitation projections that are available from climate models is an appropriate approach for determining rainfall when designing large culverts for future conditions Benefit-cost analysis using the Monte Carlo process is a useful way to deal with climate uncertainties influencing major projects
Bridge Over Navigable Waterway Exposure to Sea Level Rise	Cochrane-Africatown USA Bridge	The navigational clearance is vulnerable to only the highest sea level rise projection	Restrict ship heights Re-configure seaward ports to handle more vessels Replace with higher bridge at the end of the life-span Monitor sea level and act accordingly	Port and transportation planners should monitor and consider sea level rise and its impacts on navigation constraints beginning as soon as feasible
Bridge Approach Embankment Exposure to Sea Level Rise	US 90/98 Tensaw-Spanish River Bridge – western approach	The embankment is temporarily vulnerable to wave run-up from the projected sea level rise Vulnerable to permanent inundation under highest sea level rise projection	Continue maintenance to ensure proper function of existing riprap slope protection Raise the elevation of the riprap slope protection, approach road, and bridge Extend the embankment slopes (20:1)	Any protection recommended for a facility of this type would need to address all potential stressors upon the abutment including storm surge and scour The general analytical methods demonstrated here can be applied to other coastal embankments

Case Study Name	Facility	Was it Vulnerable?	What Options are Viable?	Take-Away
Bridge Abutment Exposure to Storm Surge	US 90/98 Tensaw-Spanish River Bridge – western abutment	Not vulnerable	No action required for erosion from storm surge at this location; however, for other abutments: • Control the approach and departure flow to realign water passage though the waterway • Armor the bridge opening • Widen, lengthen and / or shift bridge • Control drainage from the embankment and roadway to avoid erosion in the abutment area	Formulas for estimating abutment scour are very conservative, especially for typical coastal conditions leading agencies to protect foundations rather than design foundations to resist the predicted scour Inspectors should be informed that even if the structural portion of an abutment is situated on "dry" ground, other components such as bulkhead, riprap, or other stability measures may play a key role in the overall scour resistance of the abutment and should likewise be monitored
Bridge Segment Exposure to Storm Surge	US 90/98 ramp to I-10 eastbound at exit 30	Superstructure at Bents 11 and 13 would likely have bolt failures at the bottom of the girders and lift off under all storm surge scenarios investigated. It is likely that this failure could occur at any of the spans within the study section of the ramp. The piles have sufficient axial capacity to resist the uplift force on the superstructure, but the piles are not able to resist the lateral forces (shear and moment) under any of the scenarios and may fail due to shear and / or bending	Design to break away (AASHTO) Strengthen the bolt connections Install open grid decks Design shallower girder sections Use open rail parapets Replace the lower bridge segments with protected embankment (shorten the bridge)	The worst case storm surge scenario does not necessarily translate to the worst effect on the facility

Case Study Name	Facility	Was it Vulnerable?	What Options are Viable?	Take-Away
Road Alignment Exposure to Storm Surge	I-10 (mileposts 20 to 25)	I-10 can overtop under the two highest projections Underpasses subject to erosion under all projections	Harden one or more of the underpasses Armor I-10 roadway embankment Raise the roadway	Roadway embankment breaching is an area with little research data on prediction methods Additional erosion protection should be considered when designing roadway crossings that could be subjected to reverse flow from storm surges
Coastal Tunnel Exposure to Storm Surge	I-10 (Wallace) Tunnel	The tunnel is vulnerable to flooding during storms of return periods of 75 years or greater	Raise the west portal wall to elevation 19 feet Raise all approach walls to elevation 19 feet Install "temporary" flood gates	When evaluating the impacts of storm surge, wave height must be included in the analysis The Saffir-Simpson Hurricane "Category" Scale was not particularly valuable for engineering decisions because it is wind-speed based, not surge based
Shipping Pier Exposure to Storm Surge	McDuffie Coal Terminal, Dock 1	No, not the pier itself	Adaptations should be considered to preserve critical equipment and ancillary services	Loads used to design piers are beyond expected lateral loads expected from even the most extreme storm surges

Case Study Name	Facility	Was it Vulnerable?	What Options are Viable?	Take-Away
Pavement Mix Design Exposure to Temperature Changes	Area-wide	Pavements constructed to ALDOT performance grades approach being vulnerable only to the highest temperature projections	Options to reduce rutting in hotter areas: • Use thicker pavement sections at the time of initial design • Consider PCC pavement in certain applications • Change frequency of maintenance Options to improve PCC paving in hot temps: • Minimize time to transport, place, consolidate, and finish the PCC • Use a PCC consistency that allows rapid placement and effective consolidation at high temperatures. • Protect the PCC from moisture loss at all times during placement and during its curing period ▪ Use cooled PCC, achieved by using chilled mixing water, or cooling the coarse aggregate	Monitor temperature changes, periodically update historical temperature records, and use climate projections where appropriate rather than existing historical data currently used by pavement design software
Continuous Welded Rail Exposure to Temperature Changes	Area-wide	Rail can be vulnerable under the “Hotter” narrative temperature projections	Plan and conduct on-going activities Perform regular maintenance and inspections Monitor temperature trends towards the “Hotter” narrative values Keep incident records to correlate with temperature trends Increase rail neutral temperature Ensure that ballasted tracks have sufficiently wide shoulders to support the ties	The neutral temperature currently used by the railroad would be inadvisable under the “Hotter” narrative Scenario at all future time periods. Continuing to use the adopted neutral temperature might increase the risk of sun kinks in the future.

Case Study Name	Facility	Was it Vulnerable?	What Options are Viable?	Take-Away
Operations and Maintenance Activity Exposure to Climate Change and Extreme Weather Events	Area-wide	O&M activities will be more stressed by the increases in temperature, precipitation, and extreme weather events	Consult with designers about more durable materials with consideration for likely future conditions (e.g., higher temperatures, increased rainfall intensities) Change equipment needs due to expected increases in emergency response Create stand-by contracts to increase response capacity and shorten reaction times Increase attention to erosion and sedimentation issues Improve weather information systems may be applied for year-round use to monitor precipitation and flooding. Increase cross-training of staff Stockpile materials	O&M personnel in the Gulf Coast region and elsewhere need to be prepared for the unique and continuing challenges of extreme weather particularly when it comes to cooperation between organizations

2. Background

2.1 Overview of Gulf Coast Project

Facility managers, transportation planners, and elected officials are increasingly concerned about the resilience of transportation infrastructure to a range of threats, including the threats posed by climate change and extreme weather. However, the information and tools necessary to understand, evaluate, and rank vulnerabilities remains scarce. This is particularly true as it relates to specific facilities and the assets that constitute a facility; even more scarce is information and data regarding adaptation (i.e., risk mitigation) measures, their efficacy in reducing risks, and the returns on investment that might be expected if adaptation strategies are adopted. Because many assets (e.g., rail lines, bridges, and piers) are expected to provide service for 100 years or longer, consideration of medium, and long-term climate threats is essential to ensuring safe and effective transportation services at all levels of authority (i.e., federal, state, county, and municipal) and for both publicly and privately managed assets.

Acknowledging the importance of establishing systematic, transferrable approaches for assessing and addressing vulnerability to climate and weather risks, the USDOT's Center for Climate Change and Environmental Forecasting commissioned a comprehensive, multiphase study of climate change impacts on transportation in the Central Gulf Coast region. This study, formally known as *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study* (hereafter, the "Gulf Coast Study"), is the first such study of its magnitude in the United States and represents an important benchmark in the understanding of what constitutes an effective transportation system adaptation effort.

The Gulf Coast region was selected as the focal point due to its dense population and complex network of transportation infrastructure, as well as its critical economic role in the import and export of oil, gas, and other goods. The study is funded by the USDOT Center for Climate Change and Environmental Forecasting and managed by the Federal Highway Administration (FHWA). The Gulf Coast Study includes two phases:

- **Phase 1** (2008) – During Phase 1, USDOT partnered with the U.S. Geological Survey (USGS) and the U.S. Climate Change Science Program (CCSP) to investigate potential climate change risks and impacts on coastal ports, road, air, rail, and public transit systems in the region from Mobile, Alabama to Houston/Galveston, Texas. The study assessed likely changes in temperature and precipitation patterns, sea level rise, and increasing severity and frequency of tropical storms. Phase 1 then explored how these changes could impact transportation systems. It found that a local sea level rise of four feet would permanently inundate 27% of the Gulf Coast region's roads, 9% of its railways, and 72% of its ports; higher temperatures would likely lead to more rapid deterioration of infrastructure and higher maintenance costs; more intense precipitation events could overwhelm drainage systems and cause damage and delays; and increased hurricane intensity coupled with sea level rise would pose a significant threat to infrastructure.

- **Phase 2** (nearing completion) – The purpose of Phase 2 is to provide a more detailed assessment of the vulnerability of the most critical components of the transportation system to weather events and long-term changes in climate. This work is being conducted on a single metropolitan area, the Mobile, Alabama region (see Figure 2), with the intention of making the processes used in the study replicable to other areas. USDOT is conducting Phase 2 in partnership with the Mobile Metropolitan Planning Organization, part of the South Alabama Regional Planning Commission (SARPC).

Phase 2 Study Area

While Phase 1 took a broad look at the entire Central Gulf Coast region (between Houston/Galveston, Texas and Mobile, Alabama) with a 'big picture' view of the climate-related challenges facing infrastructure, the current effort in Phase 2 focuses on Mobile, Alabama. The area of the study includes Mobile County (including Dauphin Island) and the crossings of Mobile Bay to the east to landfall in Baldwin County (Figure 2).

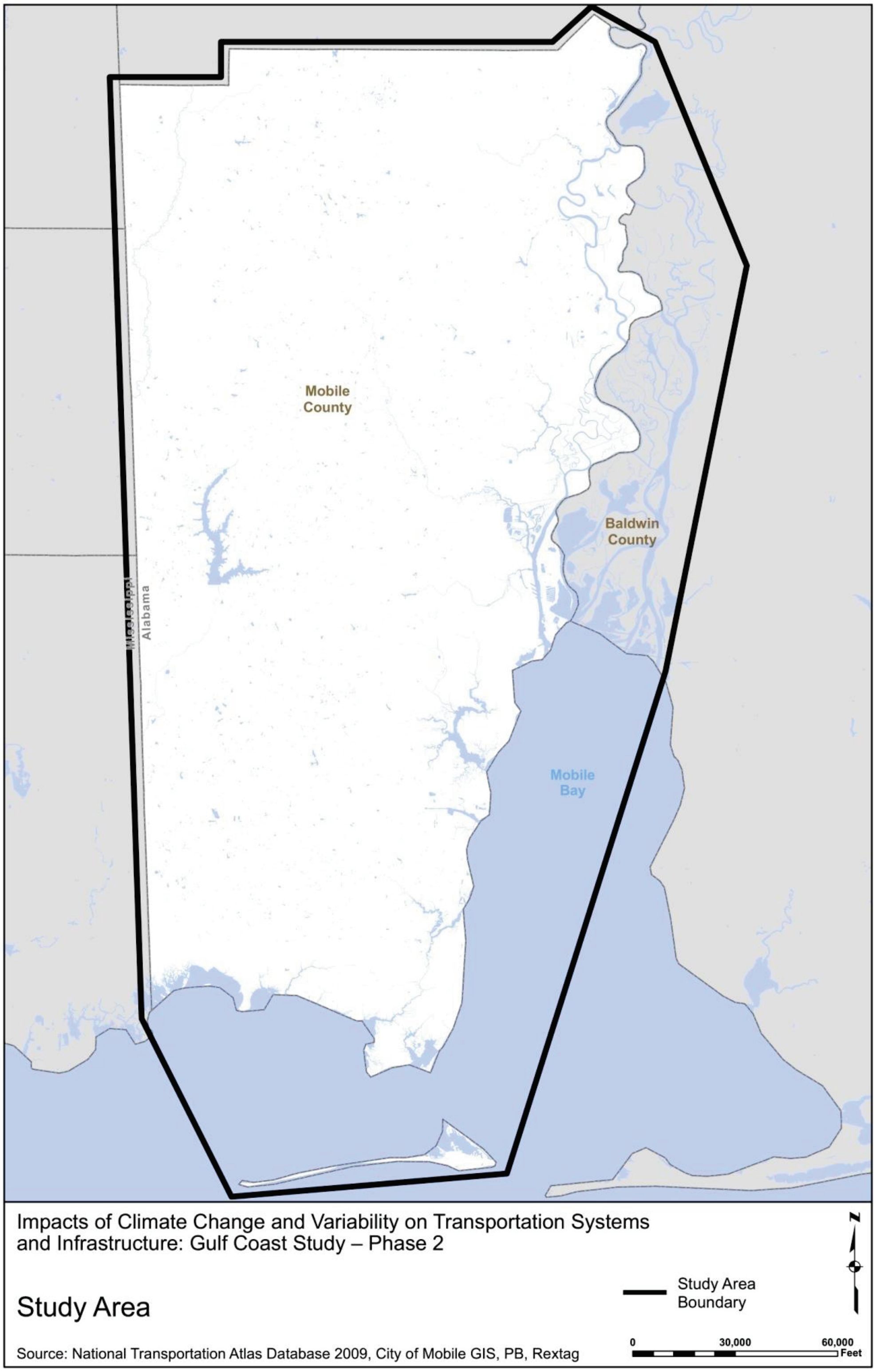
Phase 2 is divided into the tasks below. The first three tasks form the basis of a vulnerability screen and assessment of the Mobile transportation system, while the other tasks focus on tool development, coordination with stakeholders, and communication of project results.

- **Task 1: Identify critical transportation assets in Mobile.** This task (completed) served as a first level screen for the vulnerability assessment, by identifying which transportation assets are highly critical to Mobile. The results were published in the report *Assessing Transportation for Criticality in Mobile, Alabama*.[8]
- **Task 2: Develop climate information.** Task 2 (completed) focuses on characterizing how temperature, precipitation, streamflow, sea level, and storms and storm surge in Mobile could change due to climate change. This task also investigated the sensitivities of different transportation assets to each of these climate stressors, which is discussed in the companion report *Assessing the Sensitivity of Transportation Assets to Climate Change in Mobile, Alabama*.[9]
- **Task 3: Determine vulnerability of critical assets.** This task (partly covered in this report) evaluates how the highly critical assets identified in Task 1 could be vulnerable to the climate information developed under Task 2. Activities under this task led to a clearer, more systematic understanding of the key vulnerabilities of Mobile's transportation system to climate and weather factors. The methodology and findings of a high level vulnerability assessment of the transport system are covered in *Screening for Vulnerability*.[10] This report provides engineering-oriented analyses of selected vulnerable assets.
- **Task 4: Develop risk management tool(s).** Based on the findings and lessons learned during the first three tasks, Task 4 is culminating in a suite of tools and resources to assist other transportation agencies in conducting similar assessments and in managing their identified risks.[11]

[8] The Task 1 report is available at http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task1/index.cfm.
[9] The Task 2 report is available at http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task2/sensitivity_report/.
[10] The *Screening for Vulnerability* report is available at www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task3.
[11] These tools will be housed at http://www.fhwa.dot.gov/environment/climate_change/adaptation/adaptation_framework/.

- **Task 5: Coordinate with planning authorities and the public.** Ongoing throughout the project, this task focuses on engaging key local transportation stakeholders, as well as members of the public.
- **Task 6: Disseminate and publish results.** High-level findings derived from Tasks 1 through 5 will be summarized in a brief synthesis report, as well as associated presentations of the findings.

Figure 2: Gulf Coast Study Phase 2 Project Study Area



2.2 Purpose of the Engineering Assessments

This report describes the methodology and results of engineering assessments conducted on selected transportation assets in Mobile. After inventorying transportation assets in Mobile for all five modes (i.e., highway, port, airport, rail, and pipeline), conducting an assessment to prioritize critical assets (Task 1), developing Mobile-specific climate data (Task 2), and using a screening approach to rank vulnerability of critical assets to specific climate stressors (Task 3.1), the project team embarked on a series of engineering assessments.

The facilities chosen for the engineering assessment were not reflective of the most vulnerable assets, but rather they were chosen to represent a broad range of facility types and climate stressors in hopes that methods developed here might be instructive, not only for Mobile but for transportation agencies nationwide.

The purpose of the engineering assessment was twofold:

(1) Develop and test a detailed climate impact assessment process that both quantifies climate risk to a particular facility (or asset within a facility) and evaluate possible adaptation strategies that could be implemented.

(2) Explain and document Mobile-specific findings for each facility-climate stressor pair, including any findings that may apply more generally to engineering design practices, operations and maintenance practices, or other lessons learned.

A *General Process for Transportation Facility Adaptation Assessments* (the *Process*) is established and used throughout the case studies to consider a variety of climate threats for a range of asset types and modes in Mobile County. Climate threats considered in these analyses include: temperature, sea level rise, storm surge, and precipitation. Asset types and modes covered in these analyses include: rail, pavement, a shipping port pier, a culvert, bridges, a tunnel, a roadway embankment, as well as operations and maintenance.

Note that neither the *Process* nor the facility-specific findings are intended to change specific design methodologies for assets or to serve as an alternative approach for designing projects. Findings are illustrative and represent a first attempt to systematize an approach for incorporation of climate and weather risks into engineering analyses using facilities in Mobile as case studies. Also note that, although these assessments are meant to demonstrate methodologies that other transportation practitioners could use, it is not expected that any transportation agency would apply such detailed analyses to all assets under their purview. Rather, transportation agencies may wish to conduct detailed analyses on specific assets considered to be particularly critical, vulnerable, expensive to replace, due for an upgrade/replacement, etc.

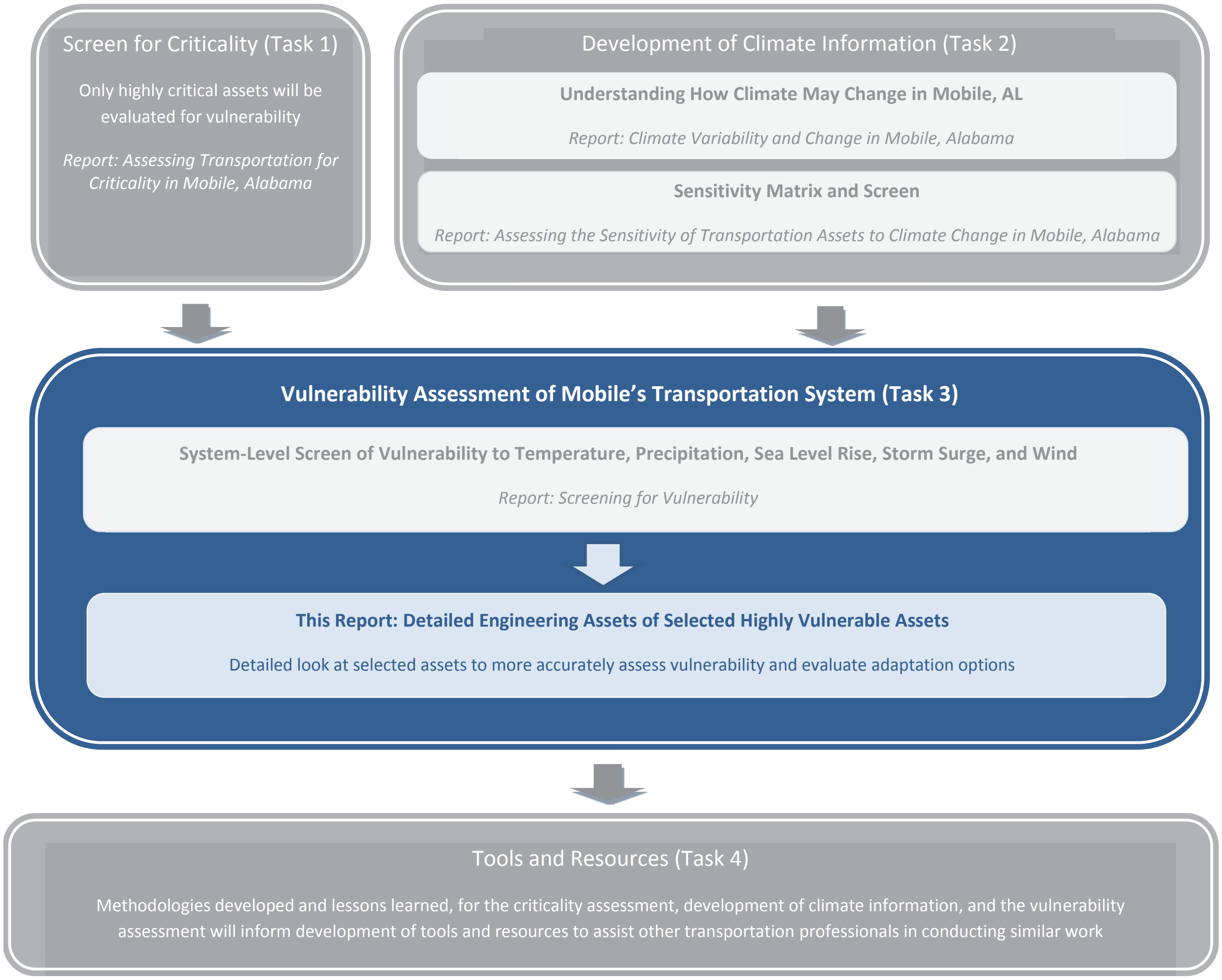
Figure 3 shows how the engineering assessments fit in with the other tasks under Phase 2.

2.3 Report Roadmap

The main body of this report is structured as follows:

- Overview of the *General Process for Transportation Facility Adaptation Assessments* used for the engineering assessments
- Case studies of engineering assessments for a variety of climate impacts on various asset types and modes in Mobile
- Overarching lessons learned
    - Key findings on the approach and defining key variables, which may be of particular interest to transportation officials considering engineering assessments in their region, and
    - Key findings of the engineering assessments on the assets in Mobile's transportation system
- Future research needs

Figure 3: Roadmap for Phase 2 of the Gulf Coast Project[12]



[12] Note: The components covered by this report are indicated with blue shading. The gray shading indicates other outcomes of the Phase 2 study that are presented in other reports and online resources.

3. A General Process for Transportation Facility Adaptation Assessments

3.1 Overview

Climate and weather[13] have always played an important role in the planning and design of transportation infrastructure; facilities of all types are planned to avoid high hazard areas whenever possible, bridges must be designed to accommodate floods, pavement must be able to tolerate extremes in temperature, etc. Traditionally, the transportation profession has relied upon historical records and statistical analyses of past climate data to inform decisions on the location and design of transportation facilities. In using historical climate data to design for future conditions, there is an inherent assumption that climate is stationary (i.e. unchanging over time).[14] Changes in climate and the frequency of extreme weather events have the potential to alter these fundamental assumptions. Climate model projections show that there could be significant changes to key environmental variables within the planned life-spans of many transportation facilities; this is particularly true for long-lived assets. These climate changes may require adaptations to the way transportation facilities are planned, designed, constructed, operated, and maintained in order to maximize functionality, safety, and the anticipated return on infrastructure investments.

Thus, the prospect of long-term changes in climate and more extreme weather presents a fundamental challenge to transportation professionals. With potential changes in climatic conditions, transportation professionals will have to grapple with new questions. For example, how much might environmental conditions change during and by the end of an asset's lifespan? At what rate will climate change take place? How can defensible, cost-effective decisions be made given the often large uncertainties involved in projections of future climate? These questions will need to be addressed on a case-by-case basis for each facility and climate change adaptation considerations may need to become standard practice when planning and designing new infrastructure.

Due to a lack of standard approaches or models for attempting this, USDOT developed a *General Process for Transportation Facility Adaptation Assessments* (the *Process*). The *Process* was developed for application on facilities found to be potentially vulnerable to climate changes

[13] Weather and climate are related in the sense that they both capture information on atmospheric conditions, however, they differ based upon the time periods referred to. Weather refers to short term atmospheric conditions as measured over time periods ranging from seconds to days and weeks. Climate, on the other hand, refers to long term patterns in atmospheric conditions; essentially, the average weather patterns for a given time period as statistically compiled from 30 years or more of weather observations.

[14] Stationarity refers to the lack of change in probabilities in a data series over time. Engineers do not assume stationarity with respect to all factors involved in design. For example, non-stationarity in watershed runoff values (e.g., due to anticipated land use changes in a drainage area) are typically considered in the design of bridges and culverts. However, with respect to the climate variables themselves (e.g., in the case of a bridge or culvert, the return period of various precipitation amounts), designers typically assume these values will remain stationary and there will be no change in the frequency of certain weather events in the future. Olson, Kiang, and Waskom (2010) provides an in-depth discussion of stationarity in the context of hydrology and water management which has broad applicability to the planning and design of transportation facilities as well.

in the *Screening for Vulnerability* report[15] produced as an earlier component of this project. That said, although the *Process* was developed in the context of this study, it is sufficiently generalizable such that it can be applied in other locations as well. The *Process* provides an 11-step framework for determining the vulnerabilities of an individual transportation facility to climate change, developing adaptation options to mitigate risks of anticipated changes, and selecting a course of action. The steps are generally as follows:

1. Describe the Site Context
2. Describe the Existing / Proposed Facility
3. Identify Climate Stressors that May Impact Infrastructure Components
4. Decide on Climate Scenarios and Determine the Magnitude of Changes
5. Assess Performance of the Existing / Proposed Facility
6. Identify Adaptation Option(s)
7. Assess Performance of the Adaptation Option(s)
8. Conduct an Economic Analysis
9. Evaluate Additional Decision-Making Considerations
10. Select a Course of Action
11. Plan and Conduct Ongoing Activities

Each of these steps is described in detail below.

The *Process* was developed to be general enough to be applied to multiple transportation modes and asset types. It can also be used both for existing facilities, where adaptive retrofits might be considered, or proposed new facilities where adaptation can be incorporated into the design. For new facilities or major upgrades to existing facilities, the *Process* can be followed during the planning and preliminary engineering phase of work so that it can influence project design decisions. For new projects, the *Process* assumes that a preliminary plan / design based on traditional practice has been developed before starting the *Process*. This preliminary plan would serve as a basis for comparison with plans that include adaptation options.

The *Process* is not intended to change specific design methodologies. The general approach to designing a culvert, for example, remains unchanged with the *Process*. What the *Process* potentially does change, however, are, (1) the climate-related inputs used in the design methodology, (2) the number and type of design options one develops, and (3) how the final option is chosen to provide a cost-effective and resilient improvement to the transportation network.

The remainder of this section provides a detailed discussion of each step in the *Process*. Next, Section 4 demonstrates how the *Process* can be applied to a variety of facility types using case study examples of potentially vulnerable facilities in the Mobile region.

[15] USDOT, 2014

3.2 The Process

3.2.1 Step 1 – Describe the Site Context

The first step in the *General Process for Transportation Facility Adaptation Assessments* involves developing a thorough understanding of the site context. The site's context is key to determining the appropriateness of various adaptation options considered in subsequent steps. Important questions that should be answered in this step include:

- What are the characteristics of the surrounding land uses, population, economic activities and significant community resources?
- For existing assets, what are the performance characteristics such as volumes / ridership, fleet mix, and role in network continuity?
- What are the characteristics of the surrounding topography and hydrography?
- Are there recognized historic resources and / or sensitive environmental resources in the area?
- What is the long-term transportation and land use plan for the area, does it account for climate change impacts, and, if so, how?
- What function does (or will) the facility serve within the broader transportation network, both in the near term and in the future (e.g., is it an evacuation route or does it provide access to an important community resource such as a hospital?)?

3.2.2 Step 2 – Describe the Existing / Proposed Facility

This step involves developing detailed knowledge on the existing or proposed facility to be studied. This knowledge is critical to developing appropriate and effective adaptation options in subsequent steps. Key information that should be gathered includes:

- Location
- Functional purpose
- Design type (e.g., box-girder bridge versus suspension bridge)
- Dimensions
- Elevations
- Proposed / remaining design life
- Age and condition (for existing assets)
- Design criteria

3.2.3 Step 3 – Identify Climate Stressors that May Impact Infrastructure Components

This step involves documenting the climate-related variables typically considered in the planning and design of the type of facility being investigated.[16] The design standards associated with these variables, if applicable, should also be noted (e.g., a state transportation department may have a policy that all bridges and their approaches must be designed to pass the 100-year storm without overtopping). Sometimes these variables affect the facility directly (e.g., temperature's influence on asphalt mix design) and in other cases they trigger other events that are the cause for concern. For example, more frequent and intense precipitation events could lead to more flooding which would need to be accounted for in bridge design. Furthermore, warmer temperatures could lead to more parasitic insects (such as the mountain pine beetle) being present in an area. The insects may kill trees in the watershed, contributing higher amounts of debris during floods that increase the chance of culverts or bridges becoming clogged.

For most facilities, several climate stressors will be relevant to designers. This can be handled in a couple of different ways when conducting facility-level adaptation assessments using the *Process*. The most thorough approach involves considering all of the climate variables as part of the same assessment. This provides the most holistic picture of climate change impacts (including their potential interactions). That said, considering all impacts can add significant effort to the assessment and may not be practicable or necessary in all cases. One alternative approach (and the one taken in this report) is to look only at the climate stressor that is likely to be most significant to the facility. This requires some degree of engineering judgment up front to determine which stressor might be most impactful. It should be noted that while this approach is appropriate in many cases, there are likely to be some instances where multiple climate stressors should be considered together, particularly if interactions are anticipated amongst the impacts. The development of adaptation options might also benefit from a holistic approach in some cases as there may be synergies (or dis-synergies) among the options that could significantly affect which options are most cost effective.

3.2.4 Step 4 – Decide on Climate Scenarios and Determine the Magnitude of Changes

After the climate-related variables that affect the facility have been identified in Step 3, the next step is to use climate model projections to determine whether and how much each of the variables of concern may change in the future. The information gathered for each variable should, if possible, relate to the design standards identified in Step 3. However, due to the limitations of current climate models and the difficulties in developing future projections, this

[16] A series of tables in the *Task 2: Climate Variability and Change in Mobile, Alabama* report (USDOT, 2012) relate specific climate variables to various transportation modes. Other useful references include (Armstrong, Keller, Flood, Meyer, and Hamlet, 2011) and the Engineering Options for Climate Stressor Mitigation tool developed as part of the *National Cooperative Highway Research Program (NCHRP) 20-83(05): Climate Change and the Highway System* project (Meyer, Flood, Keller, Lennon, McVoy, Dorney, Leonard, Hyman, and Smith, 2014).

may not always be possible in which case proxy variables may have to be substituted. Section 4.4.1 of this report provides a case study for a culvert illustrating the use of both a 100-year precipitation depth from climate models and a possible proxy for this value, the National Oceanographic and Atmospheric Administration (NOAA) Atlas 14 90% upper confidence limit, since similar climate projections are not yet available.

The future values and probability of occurrence for many climate variables are uncertain due to the inability to predict the quantity of greenhouse gases that will be emitted in the future and how precisely the Earth's climate system will respond. The *General Process for Transportation Facility Adaptation Assessments* incorporates a scenarios approach to deal with this uncertainty, an established practice in the climate change impacts assessment field. A scenarios approach involves generating a variety of climate scenarios to capture the range of possible future values of each climate variable.

Climate scenarios are typically based on assumptions regarding the amount of greenhouse gases that will be emitted into the atmosphere, a key driver in the ultimate level of climate change that will occur. Scenarios can also consider different scientific assumptions on the climate system's response to a given amount of greenhouse gas emissions (i.e., climate sensitivity) and the behavior of the climate system as captured by different climate models. Within the parameters of a scenario and the model of Earth's climate used, it is possible to develop the conditional probability[17] of a future climate event occurring, a key input to the economic analysis in Step 8. See the *Task 2: Climate Variability and Change in Mobile, Alabama* report[18] for a detailed example of how climate scenarios can be acquired or generated for a wide range of climate stressors.

As few as two scenarios showing high and low amounts of change in climate may be sufficient to capture the range of possible futures, but any number of scenarios can be utilized depending on the needs of the project. The more scenarios that are used, the more confidence one can have that all future possibilities have been considered. Practitioners should keep in mind that each scenario that is added will necessitate that additional time and resources be spent on the analysis during execution of the *Process*.

At a minimum, climate projections for each scenario should be gathered for the period extending out to the anticipated end of the facility's design life. Scenarios can also be analyzed at multiple points over the facility's design life; for example, if a facility is designed to last through 2100, it would make sense to develop scenarios for both the mid-century and end of century timeframes.

After gathering the climate projections and considering the full range of potential climate changes, it might be determined that none of the climate variables are expected to change

[17] Conditional probability refers to a probability subject to conditions, in this case, the conditions included in the chosen climate scenario.
[18] USDOT, 2012

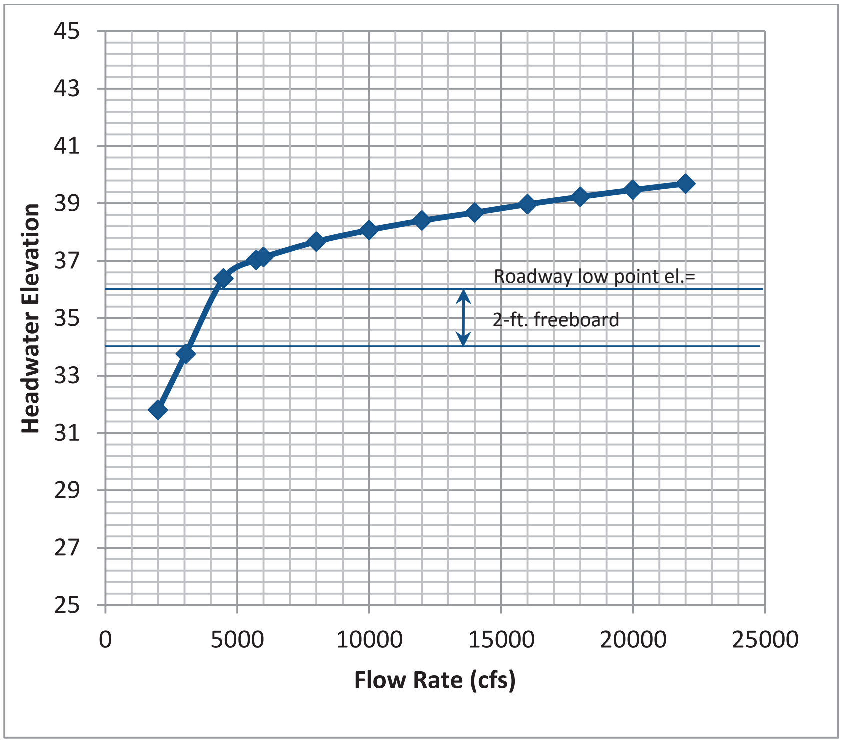
significantly or in a way that would threaten the facility. If this is the case, then the assessment is complete and no further climate adaptation analysis is required at this time. This conclusion should be reassessed periodically as new understandings and projections of future climate develop. If, however, the magnitudes of the projected change are significant, then the analysis should continue to Step 5.

3.2.5 Step 5 – Assess Performance of the Existing / Proposed Facility

The purpose of this step is to ascertain whether the existing / proposed facility is performing as expected and whether it will continue to do so under each of the possible future climate scenarios selected in Step 4. For existing facilities, the asset should be assessed with respect to current climate data to determine if the asset meets present-day design standards. Any analysis should state assumptions made regarding design standards if they are not available. This can be an important factor when deciding on whether to do adaptation or not; if the facility does not even meet present climate-related design standards, then that is further reason to undertake an upgrade.

The standards for which performance is assessed can vary depending on the asset being studied. Whenever possible, however, performance should be assessed against the design standards tied to the climate variables of interest that were noted in Step 3. For example, if a bridge and its approaches were required not to overtop during the 100-year storm, one would test each scenario's 100-year storm to determine if it overtops the facility. A graph, such as a stream stage-discharge curve for culverts or bridges (see Figure 4 for an example), can be a useful way to summarize performance.

Figure 4: Example Stage-Discharge Curve for a Culvert



In assessing impacts, one should broaden the analysis beyond narrowly looking only at the implications to the facility being studied and consider ancillary impacts caused by the subject facility's failure. For example, an undersized culvert might lead to flooding of properties upstream: these should be noted and studied. One should also determine what the implications would be (if any) on surrounding (e.g. downstream) facilities if the asset failed. These considerations are important to understand and can make a large difference in the economic analysis.

The takeaway of this step should be an understanding of which scenarios the facility performs adequately under and which scenarios it does not. One should be on the lookout for possible tipping points where damage greatly increases when the climate stressor reaches a certain level. To the extent that multiple timeframes were tested for each scenario, some sense of the timeframe around when performance is likely to fail to meet expectations will also be possible. It should be noted that the results will likely be subject to uncertainties in both the exact nature of how the climate changes will manifest themselves and precisely how the facility will respond.

At the conclusion of Step 5, it is possible that the facility is found to perform adequately under the full range of potential climate changes that it could experience throughout its intended design life: if this is the case, no further analysis is necessary at this time and the assessment is complete until new climate projections are released requiring a revisiting of this conclusion.

3.2.6 Step 6 – Identify Adaptation Option(s)

Adaptation options should be identified for each scenario that does not meet design expectations as determined in Step 5. The adaptation options could be planning or design-oriented; in many cases, the best adaptation may be to avoid a hazardous area altogether rather than to design an engineered solution. Examples of adaptive design solutions are presented within the case studies of this report. These are not meant to cover the full range of options available, but rather serve as examples of the types of actions one might consider for similarly situated facilities in other communities. A more complete list of general adaptation options for bridges, culverts, pavement, drainage systems, and slopes can be found in the Engineering Options for Climate Stressor Mitigation tool developed as part of the *National Cooperative Highway Research Program (NCHRP) 20-83(05): Climate Change and the Highway System* project.[19] It should be noted that the development of adaptation options is still in its infancy and this is an area worthy of much additional research and innovation.

In general, at least one adaptation option should be identified for each climate scenario selected. These options then become the basis for analyzing performance and decision-making. Adaptation options could consist of either one action (raising a bridge) or a package of actions that address a climate stressor or set of climate stressors (e.g., raising a bridge and armoring the approach embankments). Each option should be developed so that applicable design standards are met under the given scenario realizing that, as is the case with such standards generally, some exceptions may be necessary based on unique site constraints. Alternately, a flexible design option, whereby the design can be changed over time to respond to observed changes in conditions, may also be considered. Such an approach has the advantage of managing some of the uncertainty inherent in climate projections by avoiding committing to a certain solution until it becomes clearer that the scenario is becoming a reality. Note that there are likely to be multiple possible ways to achieve design standards under any given scenario (e.g., to accommodate higher flows through a culvert, one could add additional culverts or convert the culvert to a bridge): it is up to the project team to decide on how many options to develop and test, keeping in mind that each additional option will add additional work effort to the assessment.

Whatever approach is chosen, a high-level cost estimate to construct and maintain each adaptation option should be developed. This will be used in the economic analysis in Step 8. Although low-cost no-regrets adaptation options might be available, this is not always the case. Given the uncertainties of future climate, when adaptation involves much higher costs, some agencies might be tempted to consider a “roll-the-dice” strategy whereby proactive adaptations are not taken for existing facilities and adaptations are not made until damage occurs or planned major rehabilitation or replacement is required. The benefits and costs of such an approach can

[19] Meyer et al., 2014

be compared to those of a more proactive adaptation approach in the economic analysis discussed later.

3.2.7 Step 7 – Assess Performance of the Adaptation Option(s)

This step involves assessing the performance of each adaptation option under each potential climate change scenario selected in Step 4. This analysis is similar to Step 5 except that it is performed on the adaptation options as opposed to the existing facility or, in the case of new facilities, the standard design without adaptations. The key determination is whether each adapted facility satisfies its mandated performance standard (e.g., a 50-year design storm for a culvert) under each scenario. As in Step 5, the development of graphs such as stage-discharge curves (see Figure 4) can be a useful way to summarize this information.

3.2.8 Step 8 – Conduct an Economic Analysis

An economic analysis is of great value to informing decision-making on project level adaptation assessments. The analysis enables one to determine how the benefits of undertaking a given adaptation option, defined as the costs avoided[20] with adaptation, compare to its incremental costs under each of the possible future scenarios developed in Step 4.

The level of effort for the benefit-cost analysis should be scaled to match the magnitude of the project. Many techniques are emerging for conducting economic analyses of climate risk management strategies. Examples include Monte Carlo analysis (see Step 8 in Section 4.4.1 for an example) and the more simplified methods for scenario-based risk assessment planning discussed in Kirshen et al. (2012)[21] and *What Will Adaptation Cost? An Economic Framework for Coastal Community Infrastructure*.[22] The Federal Transit Administration (FTA) has released a *Hazard Mitigation Cost Effectiveness (HMCE) Tool* with an associated User Manual and trainings that facilitates the documentation of costs and benefits and calculates the final cost benefit ratio[23]. The approach used and the level of detail will be dependent upon the total value of the facility being studied, the technical abilities of the project team, and other resource constraints.

Whichever approach is utilized, the basic technique involves estimating the expected impact costs from climate or weather events over the life of the facility and discounting them to determine the present value of these expected costs. This is done for the base case situation of the existing facility or standard new design and repeated for each adaptation option under each climate change scenario selected in Step 4. The (lower) costs with the adaptation options in place

[20] Costs avoided might include the costs of damage to the facility, clean-up costs, costs to the traveling public due to detours and delays, death and injury costs, costs to businesses and others dependent on the transportation facility, potential costs to surrounding land uses from impacts generated by the facility (e.g., an undersized culvert resulting in upstream flooding that affects neighboring properties), and, potentially, environmental impacts generated by the facility (e.g., a coastal causeway that prevents marsh migration inland as sea levels rise).
[21] Kirshen, Merrill, Slovinsky, and Richardson, 2012
[22] Eastern Research Group, 2013.
[23] FTA, 2014.

can then be compared to the base case costs to determine the cost savings expected as a result of adaptation. The net present value and/or the benefit-cost ratio of each adaptation option can then be computed and compared among the adaptation options. The results can be presented in tables showing each adaptation option's cost-effectiveness under each scenario (see Table 3 for an example).

Table 3: Example Benefit-Cost Analysis Outputs for an Adaptation Option

Climate Scenario	1	2	3	4	5	Average (mean) of All Scenarios
Description of Scenario	Observed 1980–2009 with Current Land-use	Observed 1980–2009 with Future Land-use	NOAA 90% Upper Confidence Limit	"Wetter" Narrative	"Drier" Narrative	
Present Value of Costs	$2.5m	$2.5m	$2.5m	$2.5m	$2.5m	$2.5m
Present Value of Benefits	$10.3m	$11.8m	$18.5m	$97.5m	$8.9m	$29.4m
Net Present Value	$7.8m	$9.3m	$16.0m	$95.0m	$6.4m	$26.9m
Benefit-Cost Ratio	4.1	4.7	7.4	38.9	3.6	11.7
Probability that Benefit-Cost Ratio will be over 1	38%	44%	71%	99%	35%	N/A

Decision-makers can then consult the tables and look for (1) adaptation options that have benefit-cost ratios greater than one and (2) the adaptation option that performs best across the full range of scenarios tested (the robust option). It should be noted that the economic analysis does not in and of itself always provide an answer as to whether an adaptation option makes financial sense. There is no guarantee that an adaptation option that performs cost-effectively under each scenario will exist: an option may be cost-effective under one scenario but not another. Likewise, there may be no one adaptation option that is the most robust economic performer across all scenarios. In every case, but in these cases especially, trade-offs will have to be made and the community's and / or facility owner's risk tolerance evaluated to help choose the "best" option from a financial standpoint. Ultimately, uncertainties associated with projected changes in climate tend to magnify subjective factors during decision-making, including risk tolerance of customers and funders of transportation assets.

3.2.9 Step 9 – Evaluate Additional Decision-Making Considerations

As in other areas of transportation decision-making, the cost-effectiveness of adaptation options is not the only factor important to making wise investment decisions. Other factors that can be difficult to monetize (for benefit / cost analysis) should also be considered before a final decision is reached. These may include:

- Broader project sustainability beyond just climate change impacts (i.e., the "triple bottom line" of social, environmental, and economic concerns)
- Project feasibility and practicality
- Ongoing maintenance needs
- Maintenance funds availability
- Capital funds availability
- Stakeholders' (public and government agencies) tolerance for risk of service interruption and associated costs of all types (note: this affects how the economic analysis is perceived as well)
- Stakeholders' expected quality or level of service

Much of this information will need to be gathered through community outreach and stakeholder engagement processes.

3.2.10 Step 10 – Select a Course of Action

Once as much information as possible has been gathered on both economic and non-economic factors, decision-makers should weigh the information presented and decide on a course of action. Those involved should keep in mind that adaptation does not always make sense from a financial feasibility or community acceptance standpoint and a decision to take no action may be justified in some cases.

3.2.11 Step 11 – Plan and Conduct Ongoing Activities

Once a decision has been made on a course of action, a management plan for the facility should be developed. At a minimum, the management plan should contain an element of monitoring to determine if the facility is performing as expected over time. If an adaptation option was used, estimates of the costs saved from implementing the adaptation could be developed so that the benefits of the adaptation are documented and compared to its costs. This information could prove beneficial in future years as the community continues to make decisions on which adaptations, if any, make sense in various situations.

4. Case Studies

4.1 Introduction

Ten case studies were conducted to demonstrate the application of the *General Process for Transportation Facility Adaptation Assessments* (the *Process*) to a range of design problems at 10 specific facilities in Mobile. In addition, operations and maintenance (O&M) opportunities for adaptation were examined in a final case study. These case studies illustrate how engineering design processes may be augmented to incorporate climate change and extreme weather considerations.

The primary criteria for selecting an asset or facility in the case studies included:

- The facility's relative vulnerability ranking as determined in the *Screening for Vulnerability* report.[24] These screening-level results include the magnitude of the direct and secondary consequences of failure or interruption as a factor.
- Diversity in the range of modal assets and facilities being examined
- Degree to which lessons learned and processes illustrated for a given asset/facility could be applied elsewhere in the Gulf Coast or the nation
- Availability of non-proprietary information (existing plans and design data) for the subject asset
- Available resources

4.2 Selection of Cases

Table 4 lists the climate stressors and asset types chosen for study and the specific case study facilities that were investigated. Figure 5 shows the location of these facilities.

4.3 Approach

Since the case studies are intended to demonstrate the application of the *Process*, each case study is structured using the 11 steps of the *Process* (see Section 3.2 for a detailed discussion of each step). The step-by-step summaries thus provide detailed examples of how the *Process* can be applied to a variety of climate stressors and facility types.[25]

The projected climate data used in the case studies were developed during earlier tasks of this project. For more information on how the climate information was developed and packaged into climate "narratives" for purposes of vulnerability assessments, please see the Task 2 and Task 3.1 reports at www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_

[24] USDOT, 2014
[25] Detailed calculations and model outputs are not included in this report, but are available upon request by contacting the FHWA authors of this report.

research/gulf_coast_study/phase2_task2/sensitivity_report/ and www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task3.

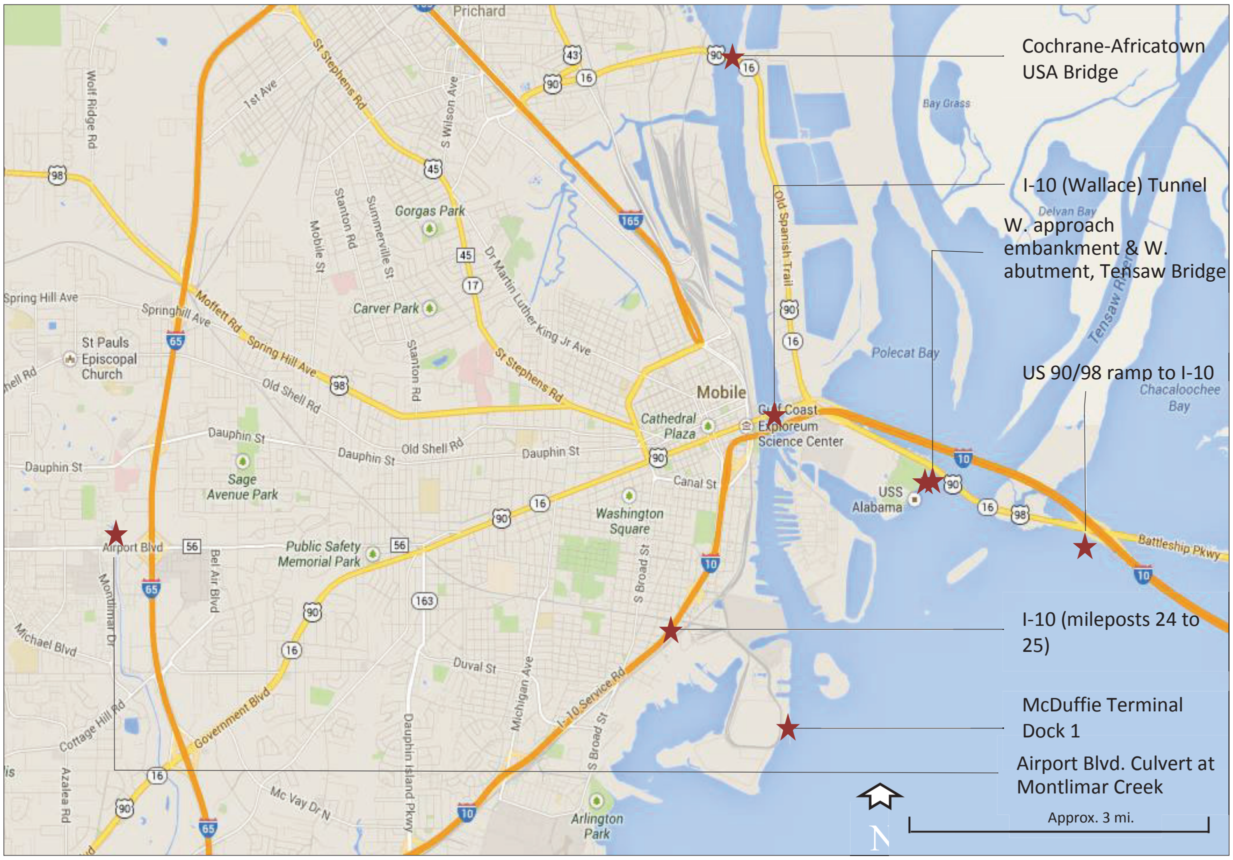
Due to the nature of this project as a broad study across many facilities, none of the case studies represent a full application of every step in the *Process*. For example, none of the cases included a full evaluation of additional decision-making considerations in Step 9, as public outreach related to specific adaptation measures was beyond the scope of this project. In addition, only the study of a culvert exposed to changes in precipitation patterns (Section 4.4.1) included an economic analysis. Recognizing these limitations, the selected courses of action discussed in Step 10 of each case study are preliminary recommendations, subject to additional findings from completion of full economic analyses and outreach with local stakeholders.

Table 4: Listing of Case Studies by Climate Stressor, Facility Type, and Damage Mechanism

Report Section	Climate Stressor	Asset Type	Damage Mechanism	Case Study Facility	**Indicator-Based Vulnerability***
4.4.1	Increased precipitation	Culvert	Flooding	Airport Boulevard culvert at Montlimar Creek	Low
4.4.2	Sea level rise	Navigable waterway bridge	Clearance for navigation	Cochrane-Africatown USA Bridge	Medium
4.4.3	Sea level rise	Bridge approach embankment	Slope erosion	West approach embankment of the US 90/98 Tensaw-Spanish River Bridge	High
4.4.4	Higher storm surge	Bridge abutment	Abutment scour	West abutment of the US 90/98 Tensaw-Spanish River Bridge	Medium
4.4.5	Higher storm surge	Bridge segment	Wave forces, bridge pier scour	US 90/98 ramp to I-10 eastbound at Exit 30	High
4.4.6	Higher storm surge	Road alignment	Overtopping / slope erosion	I-10 (mileposts 24 and 25)	Low
4.4.7	Higher storm surge	Coastal tunnel	Flooding	I-10 (Wallace) Tunnel	Medium
4.4.8	Higher storm surge	Shipping pier	Waves	McDuffie Coal Terminal, Dock 1	Low
4.4.9	Temperature changes	Roadway pavement	Rutting, concrete crackings	Generic location	Low
4.4.10	Temperature changes	Continuously welded rail	Buckling, pull-aparts	Generic location	Medium
4.4.11	Various	Operations and maintenance activities for various facilities	Various	Alabama Department of Transportation, City of Mobile, and Mobile County operations and maintenance practices	High

* An asset's estimated vulnerability was calculated previously in this project, as detailed in the report *Task 3.1: Screening for Vulnerability*. The vulnerability designations developed within the *Screening for Vulnerability* report provide initial estimates of an asset's vulnerability to a particular climate stressors based on a series of vulnerability "indicators" applied broadly across the transportation system. However, in this *Task 3.2 Engineering Analysis and Assessment* report, the more refined engineering analyses performed may result in different determinations as to an asset's actual vulnerability.

Figure 5: Case Study Locations[26]



Also, the case studies are very specific to one type of asset for one type of climate stressor at a particular location. It was beyond the scope of this analysis to include all components of a facility design when considering adaptation strategies, or to consider the entire range of climate stressors that might affect each case study facility over time. Instead, the climate stressor that is likely to be most impactful was chosen for study. Actual project-level applications of the *Process* may, however, attempt to be holistic in their consideration of climate impacts. All relevant components of a facility that could be impacted by climate change may be considered in these studies, including an assessment of how climate change may impact the land uses being served by that facility and vice versa. Complex interactions between land use, demographics, and changes in climate will all influence the demand on the facility; understanding the local context and the relative influence of these factors is critical to making informed adaptation decisions. Similarly, considering the possible interrelationships of various climate stressors may be important when undertaking actual assessments.

Lastly, it should be noted there are several key facilities in the transportation system that were not included as case studies. This includes highway and railway signs and signals,

[26] Source of base map: Google Maps (as modified)

communication networks, power supplies to all major transportation facilities, and other key components of the system. Additional assessments will be needed to determine how best to adapt the design of these facilities to a changing climate.

4.4 Individual Case Studies

4.4.1 Culvert Exposure to Precipitation Changes – The Airport Boulevard Culvert over Montlimar Creek

Introduction

Culverts are an important and sometimes underappreciated component of the highway system that can be highly sensitive to climate change. This section of the report illustrates how the *General Process for Transportation Facility Adaptation Assessments* can be applied to culverts by using the Airport Boulevard culvert over Montlimar Creek (see Figure 6) as a case study. The goals of this assessment are to (1) determine whether projected changes in precipitation patterns associated with climate change will pose a flood risk to the facility and, if so, (2) to develop and evaluate adaptation options for managing that risk. This case study does not go into all the details of the culvert design process, but rather focuses on one particular design consideration that is affected by climate change; precipitation and its impact on streamflow.

Case Study Highlights

Purpose: Evaluate whether culvert design is sufficient under projected levels of 24-hour precipitation

Approach: Using projected 24-hour rainfall values and NOAA temporal rainfall distributions, peak flows to the culvert were modeled using the Win TR-20 Program, considering both existing and future land use conditions. Then, hydraulic analyses were conducted to determine the performance of the culvert under current and future flows, using the HY-8 Version 7.2 program. Performance was assessed by determining whether at least 2 feet of freeboard would be achieved during a 25-year event, which is the standard used by the city of Mobile for this type of culvert.

For each adaptation option, flooding impacts of a 100-year event on surrounding areas were evaluated. An economic analysis of adaptation options was conducted using a Monte Carlo process.

Findings: Culvert design is sufficient for current conditions, but the roadway could be overtopped under projected future conditions

Viable Adaptation Options:

- Increase number of culvert cells
- Increase size of culvert cells
- Implement Regional Drainage Area Management practices

Other Conclusions: An economic analysis could be done using a Monte Carlo process, which is effective in managing the uncertainties associated with the climate projections. For this case study, the economic analysis indicates that increasing the number of the culvert cells is more likely to be cost-effective under various climate futures than increasing the size of the culvert cells.

Figure 6: Photo of the Airport Boulevard Culvert over Montlimar Creek, Upstream Side

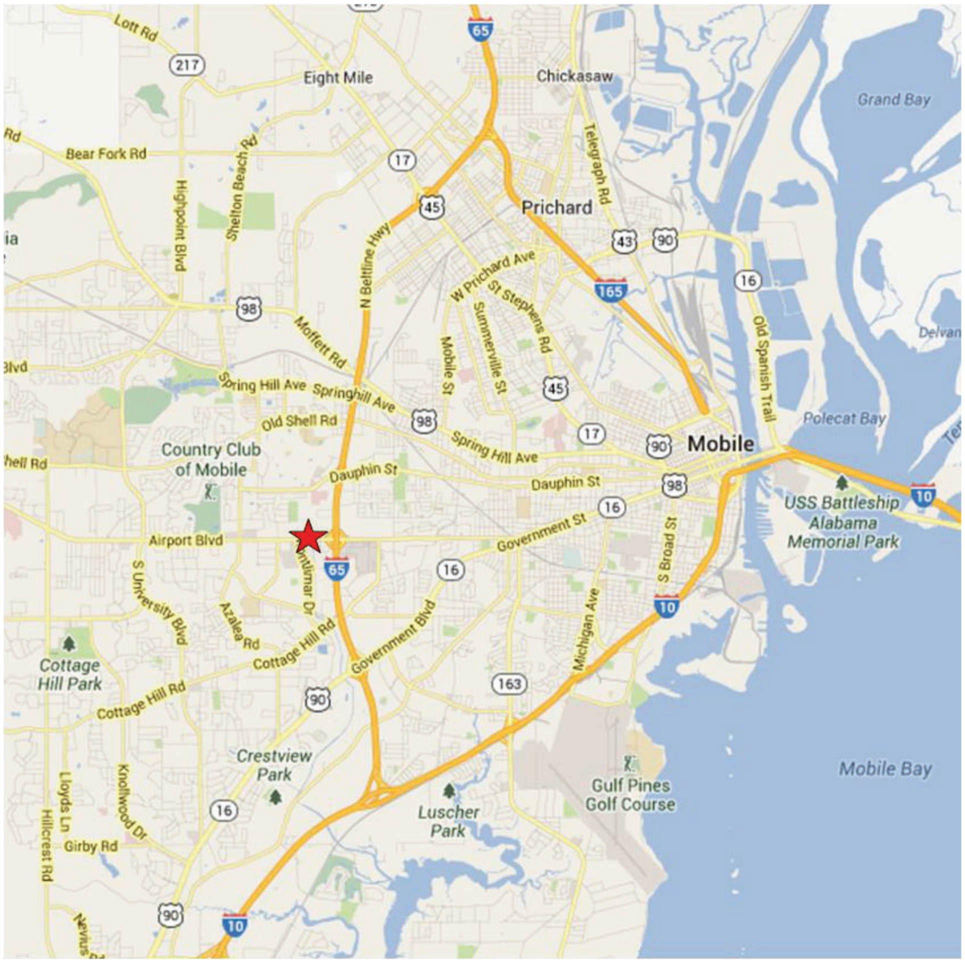
Adaptation options considered for handling projected increases in streamflow include adding two additional cells to the existing culvert or raising the road and replacing the existing culvert with one that has larger cells. Unlike the other case studies, this case study also includes an economic analysis to show how one might use the financial performance of each adaptation option developed to aid in decision-making. Based on this analysis, the preliminary recommended action is to expand the culvert by adding two additional cells to the existing facility. The case study concludes with lessons learned about the application of the *General Process for Transportation Facility Adaptation Assessments* to culvert design. As with any culvert design, the designer must consider the culvert as an element within the drainage *system* and determine the effectiveness of and the influence on performance of all of the drainage system elements.

Application of the General Process for Transportation Facility Adaptation Assessments

Step 1 – Describe the Site Context

The Airport Boulevard culvert over Montlimar Creek is located on the west side of the City of Mobile (see Figure 7) immediately to the west of Airport Boulevard's intersection with I-65. Airport Boulevard is a major six-lane east-west arterial linking downtown Mobile with its western suburbs and the regional airport (located approximately seven miles to the west). The main road is flanked by a pair of two-lane bi-directional frontage roads that also utilize the culvert. The two primary regional shopping centers, the Springdale Mall and the Bel Air Mall, are immediately to the east of the I-65 interchange, adding to the traffic loads on the facility. In addition to personal and commercial vehicles, Wave Transit System bus routes 1 and 18 use the segment of Airport Boulevard passing over the culvert.

Figure 7: Location of the Airport Boulevard Culvert within the Mobile Metropolitan Area[27]



The roadway network in the vicinity of the culvert is fairly dense with Dauphin Street providing an alternative crossing of Montlimar Creek about 0.6 miles to the north and Michael Boulevard and Pleasant Valley Road crossing the creek approximately one mile to the south. Alternative stream crossings are an important consideration when evaluating possible detour routes if Airport Boulevard is closed due to inundation.

Hydrologic Setting

Montlimar Creek is a man-made feature that was designed as a drainage canal through Wragg Swamp, a wetland that once existed in the area surrounding the I-65 interchange with Airport Boulevard. Figure 8 shows two historical topographic maps illustrating the swamp and the major changes to the area's hydrology that came with the construction of I-65 and urbanization of the area. The figure shows that the Eslava Creek once flowed eastward through Wragg Swamp prior to the construction of I-65, at which time the creek was bifurcated into separate branches west

[27] Source of base map: Google Maps (as modified).

and east of the interstate. The east branch of Eslava Creek continued in a southeast direction to the Dog River; the west branch was channeled southward into what is now the Montlimar Creek, keeping all these waters to the west of I-65 before draining into the Dog River.

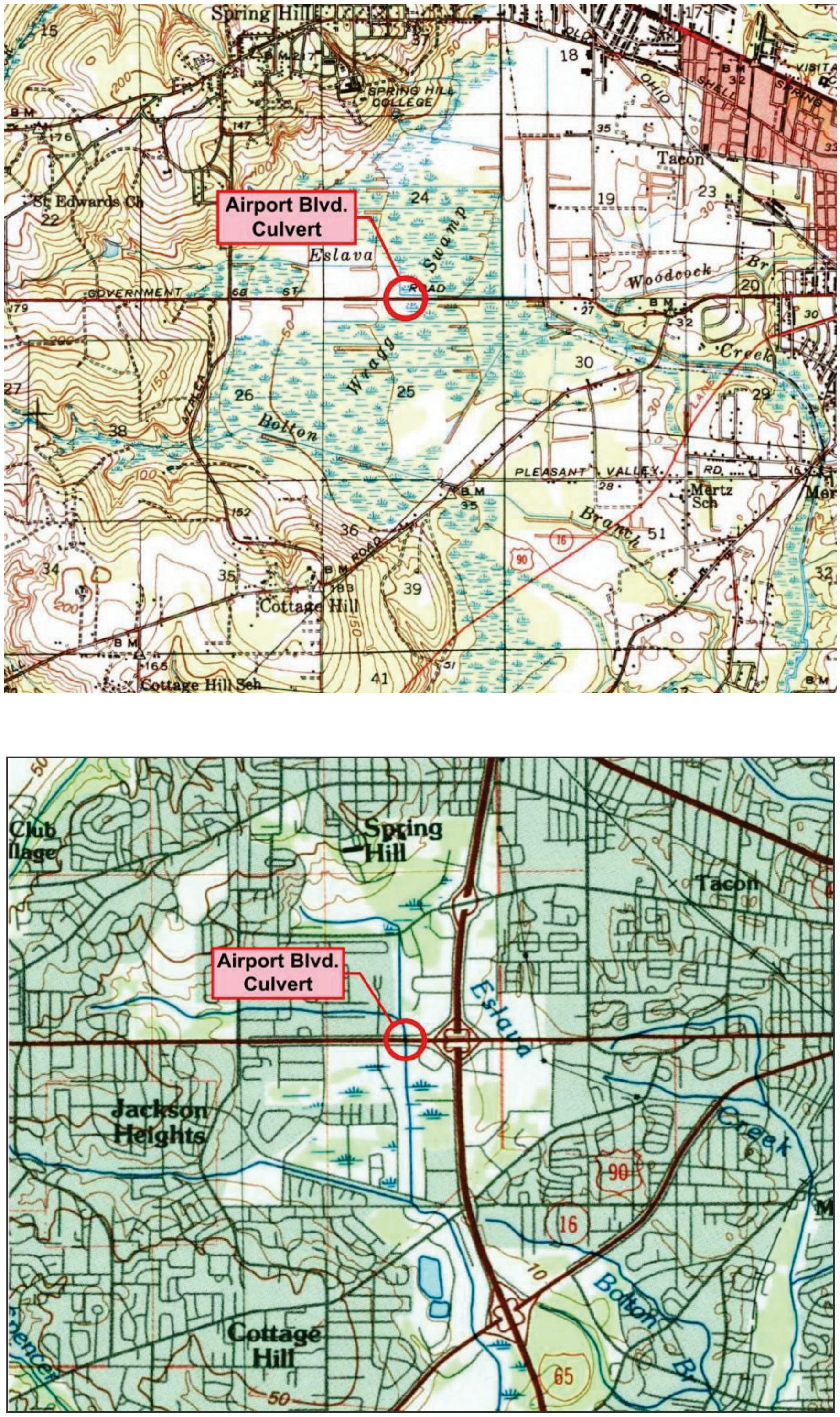
Figure 9 shows the present-day drainage area for water flowing through the Airport Boulevard culvert. The total drainage area to the culvert is 3.3 square miles (8.5 square kilometers).

Today's Montlimar Creek consists of a series of man-made channels surrounded by urban development. The segment just upstream and downstream of the Airport Boulevard culvert is a trapezoidal channel with grassy vegetation on the side slopes. The surrounding area consists almost entirely of paved commercial areas. The channel has an approximate top width of 120 feet (36.6 meters) and an approximate depth of 10 feet (3 meters). The bottom width is approximately 40 feet (12.2 meters) and side slopes are 25%.

The Airport Boulevard culvert over Montlimar Creek lies within a Federal Emergency Management Agency (FEMA) regulated floodplain. Figure 10 shows the 100-year (1% annual chance) and 500-year (0.2% annual chance) floodplain boundaries developed based on the FEMA flood insurance study for Mobile County.[28] Importantly, the flood boundaries presented in the FEMA flood map do not account for the area east of the culvert. According to the flood insurance study, the flood elevations for Montlimar Creek at Airport Boulevard were determined to be approximately 37 and 38 feet (11.3 and 11.6 meters) for the 100-year and 500-year floods, but the floodplain boundaries do not include the area to the east of the culvert which sits at a lower elevation. Further investigation into flood elevations and extents using hydrologic analysis methods is discussed in subsequent sections.

[28] FEMA, 2010d

Figure 8: Topographic Maps from 1940 (Top) and 1994 (Bottom) Illustrating the Significant Changes to Local Hydrology with the Construction of I-65 and Urbanization[29]



[29] Source of basemaps: USGS, 2012 (as modified). Note: Maps not to scale.

Figure 9: Drainage Area to the Airport Boulevard Culvert Showing LIDAR Contours and Time of Concentration (Tc) Path

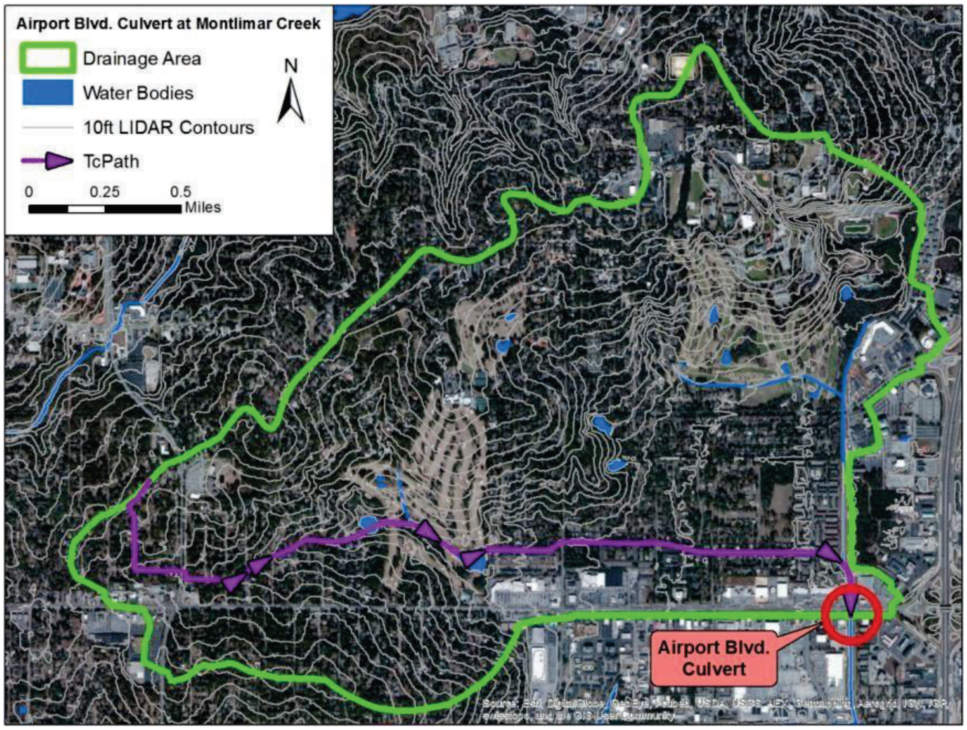
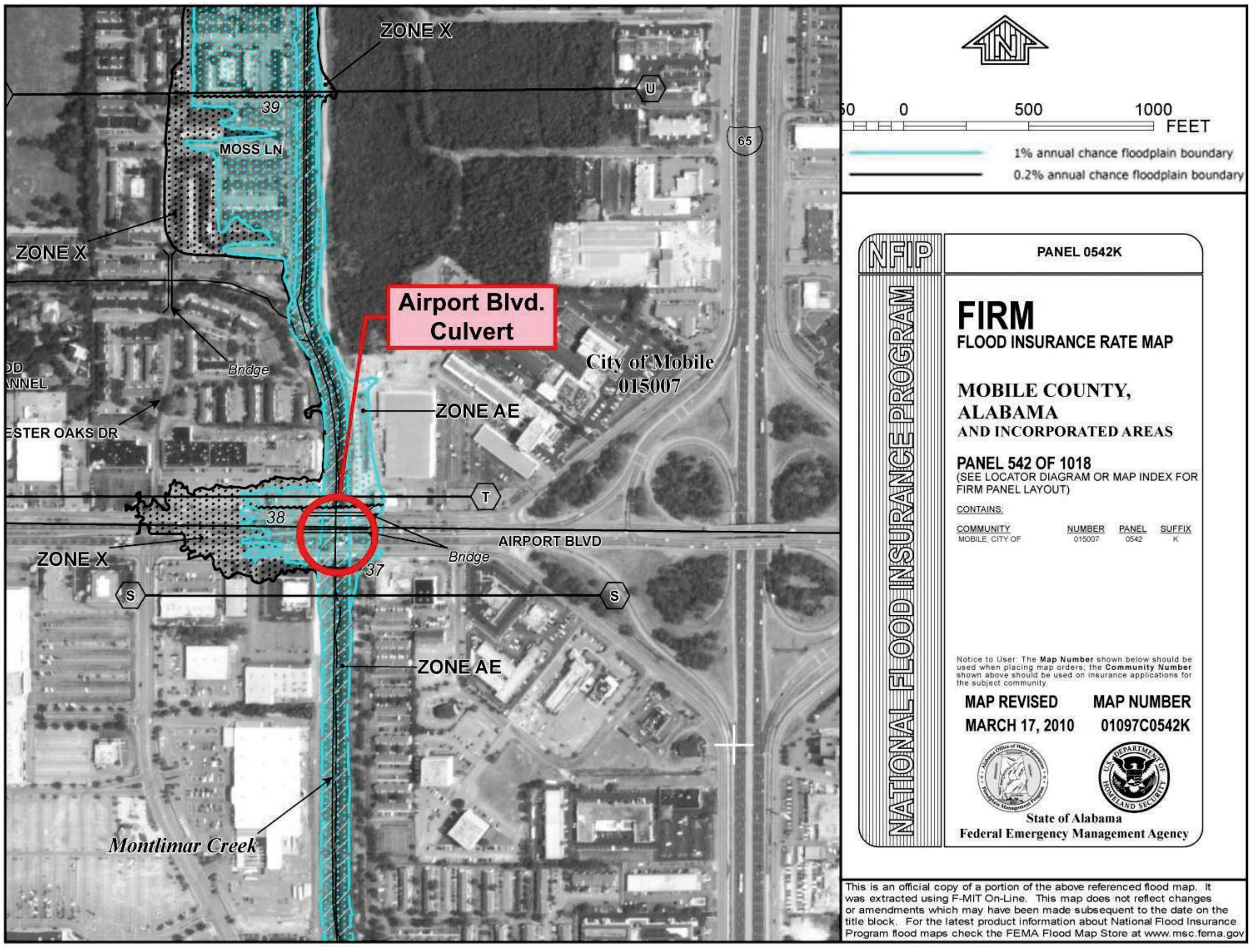


Figure 10: FEMA 100-Year (1% Annual Chance) and 500-Year (0.2% Annual Chance) Floodplains near the Airport Boulevard Culvert [30]



Step 2 – Describe the Existing Facility

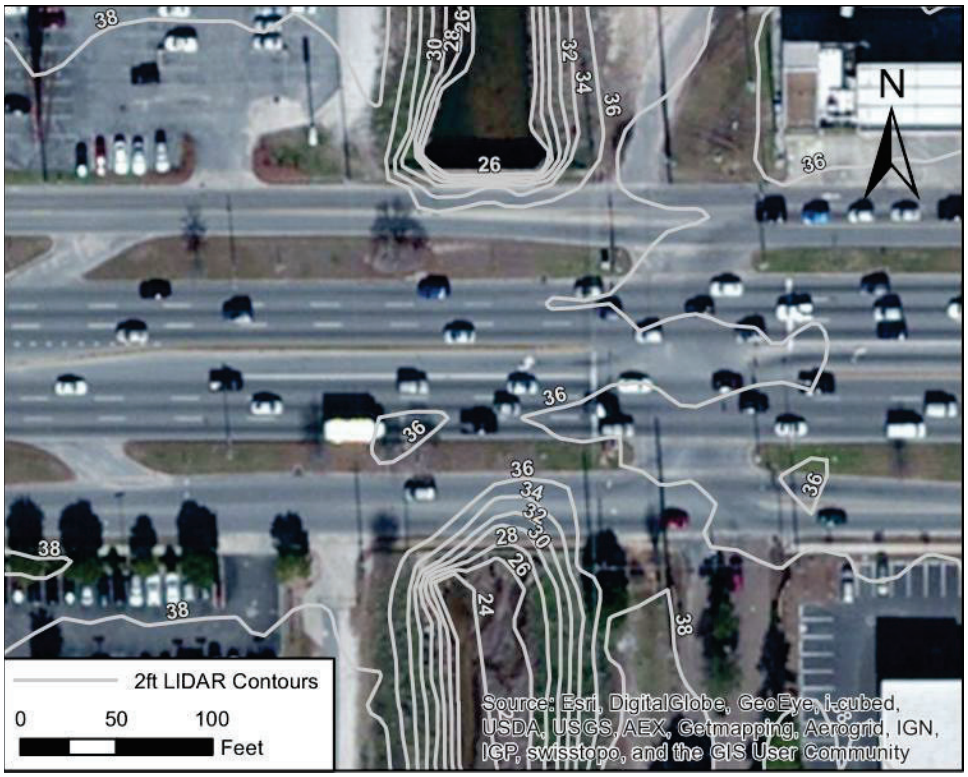
The Airport Boulevard culvert is owned and maintained by the City of Mobile. According to 2009 field inspection data provided by the City,[31] it was built in 1960. The longitudinal length of the culvert was originally approximately 70 feet (21.3 meters). A subsequent widening of Airport Boulevard lengthened the culvert by 65 feet (19.8 meters) north and 65 feet (19.8 meters) south to today's total length of 200 feet (61 meters). Figure 11 shows a plan view of the culvert crossing. Figure 12 and Figure 13 are photos of the culvert taken in June 2013. The culvert was designed for a 25-yr. storm with the maximum allowable headwater 2 feet (0.61 meters).

Figure 14 provides a diagram of the facility showing its current dimensions.

[30] FEMA, 2010a
[31] City of Mobile, 2009

The structure is a four cell concrete box culvert with each cell having a 12 foot (3.7 meter) span (width) by eight foot (2.4 meter) rise (height). The fill depth to the roadway was measured to be two feet two inches (0.7 meters). The slope of the culvert from its inlet to its outlet was not available from project data but was measured to be approximately 1% based on LIDAR contours. Based on the 2009 field inspection (performed at some time subsequent to the lengthening), the culvert was in generally sound condition. It was determined at the time that there were no deficiencies that would affect the load bearing capacity of the culvert, but there was some spalling[32] of the concrete and exposed rebar in multiple locations at the top face.

Figure 11: Plan View of the Airport Boulevard Culvert Crossing Showing LIDAR Contours

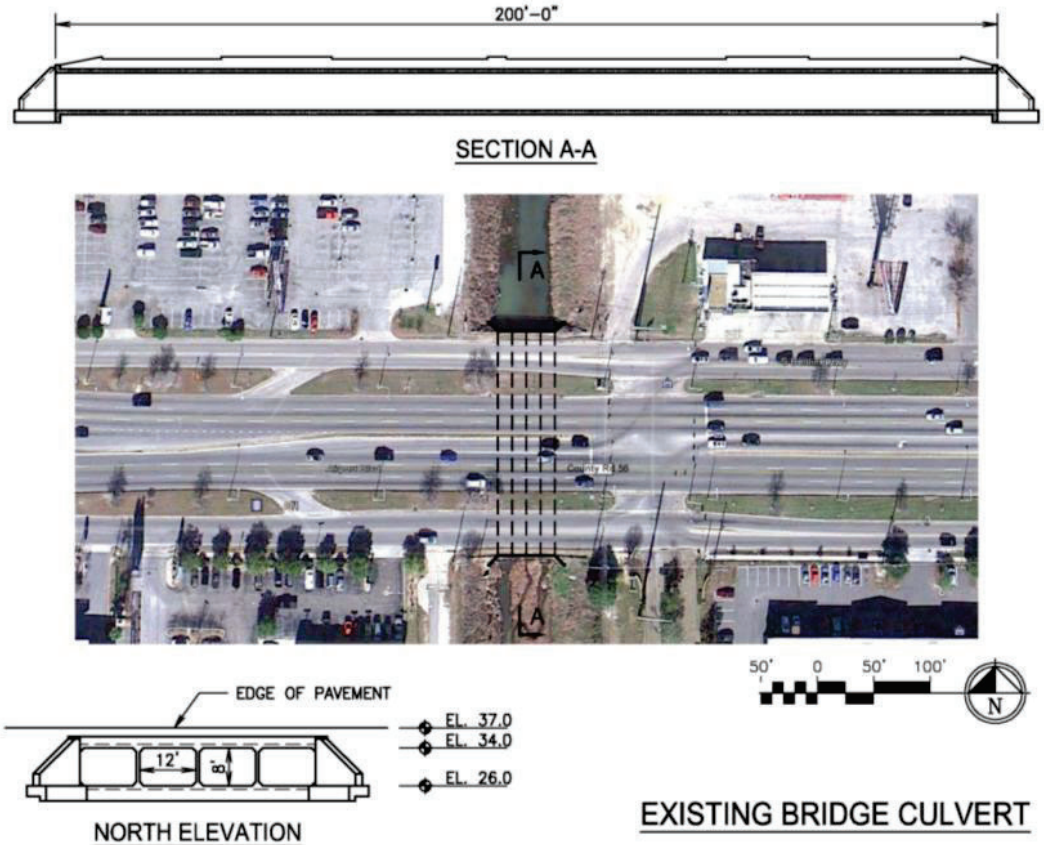


[32] Spalling refers to a deterioration condition of older concrete where fragments of the concrete material face have broken off. Spalling is usually caused by corrosion of the steel reinforcement bars embedded in the concrete.

Figure 12: Photo of the Airport Boulevard Culvert over Montlimar Creek, Upstream Side

Figure 13: Photo of the Airport Boulevard Culvert over Montlimar Creek, Downstream Side

Figure 14: Plan for the Airport Boulevard Culvert over Montlimar Creek



Step 3 – Identify Climate Stressors That May Impact Infrastructure Components

In this culvert study, precipitation (and the resulting flow) is the primary environmental factor affecting the design that is expected to be affected by climate change. Accordingly, precipitation is the environmental factor selected for this analysis.

Step 4 – Decide on Climate Scenarios and Determine the Magnitude of Changes

Four precipitation scenarios were considered for this adaptation assessment based on current climate and projected climate changes:

- Observed precipitation values (1980-2009).
- The NOAA Atlas 14 90% Upper Confidence Limit.
- The "Wetter" narrative precipitation ranges developed under this project using downscaled climate data for Mobile County and a range of climate scenarios.[33]
- The "Drier" narrative precipitation ranges developed under this project using downscaled climate data for Mobile County and a range of climate scenarios.

[33] For more information on the climate information referenced here, please refer to *Climate Variability in Change in Mobile, AL* (USDOT, 2012) and *Screening for Vulnerability* (USDOT, 2014).

All four scenarios considered 24-hour precipitation depths as this is the shortest storm duration reported from the available climate models for future conditions. Return periods[34] analyzed include the two-, five-, 10-, 25-, 50-, and 100-year storm. The range of 24-hour precipitation values for each scenario and return period is shown in Table 5, along with the NOAA Atlas 14 Average Baseline value for comparison. Table 6 shows how the projected precipitation values would translate to present date return periods.

A standard culvert design project would typically rely upon the average precipitation data as presented by the NOAA Atlas 14 Average Baseline. However, to provide consistency in this study with the work performed under prior project tasks and the modeled climate projections, the Atlas 14 data was not utilized as the current baseline condition. Instead, the Observed precipitation values represent the model baseline precipitation values as documented in the *Climate Variability in Change in Mobile, AL* report.[35] The observed data comprise the average modeled values across the five weather stations in the Mobile area. The project team considered using the observed data for the station closest to the project site (the Mobile station) but found that the average across all five stations more closely matched the NOAA Atlas 14 estimates for the site location. The use of the five station aggregate also provides the advantage of having a larger sample data set to draw from over the course of the observation time period (1980-2009): 145 peak yearly precipitation values, versus 29 peak yearly precipitation values (one for each year) for a single site. The compilation of a larger data set allows for improved accuracy in the prediction of return period storm events, particularly for rarer, more severe storm events.

The NOAA Atlas 14 90% Upper Confidence Limit scenario was chosen to provide a contrasting increased precipitation intensity scenario that relies on the use of historical observations. This scenario is not derived from climate models and does not represent theoretical or projected climate conditions. Instead, it represents the upper range of precipitation depths based on statistical analysis of historical observations. NOAA included these confidence intervals in its Atlas 14 to acknowledge the fact that there is uncertainty even in precipitation depth estimates derived from historical data. Typical engineering practice makes use of the average estimate values from NOAA Atlas 14 and does not consider the upper bound of the 90% confidence interval, which provides a greater precipitation depth than the point estimate for the average. Use of the upper bound estimate from NOAA Atlas 14 is a potential alternative proxy approach, consistent with engineers' traditional use of historic data (as compared to use of climate model projections), for considering changes in precipitation intensity and frequency under various future climate scenarios. Note that in this scenario, the probabilities of each return-period event are necessarily assumed to remain constant throughout the 21st century, something climate modeling may show is not necessarily the case in many areas.

[34] A return period, or recurrence interval, is defined as the inverse of the probability of occurrence for a flood event in a given year; i.e., a 100-year storm would be a storm that has a 1% chance of occurring during any given year.
[35] USDOT, 2012

Table 5: 24-Hour Precipitation Depths Used in the Airport Boulevard Culvert Hydrologic Analysis

24-hour Storm Event Return Period	Observed (Model Baseline) 1980–2009 (inches)[36]	NOAA Average Baseline (inches)[37]	NOAA 90% Upper Conf. Limit[38]	"Wetter" Narrative			"Drier" Narrative		
				2010–2039 (inches)	2040–2069 (inches)	2070–2099 (inches)	2010–2039 (inches)	2040–2069 (inches)	2070–2099 (inches)
100-yr storm	13.5	14.9	18.9	21.0	20.4	22.3	12.6	14.2	13.4
50-yr storm	12.5	12.8	15.9	19.1	18.5	20.2	11.7	13.1	12.5
25-yr storm	10.1*	10.9	13.4	15.7*	15.2*	16.7*	9.3*	10.4*	9.9*
20-yr storm	9.5	Unavailable	Unavailable	14.8	14.4	15.8	8.8	9.9	9.4
10-yr storm	8.5	8.6	10.1	12.9	12.5	13.7	7.9	8.8	8.4
5-yr storm	7.1	7.1	8.3	10.5	10.3	11.1	6.6	7.3	7.0
2-yr storm	4.8	5.3	6.2	6.7	6.7	7.1	4.4	4.8	4.6

* Asterisks denote interpolated values[39]

[36] These values represent the baseline precipitation values from the climate models averaged across the five weather stations in the Mobile area. The source data is from Table 40 in USDOT, 2012.
[37] Based on NOAA Atlas 14 annual maximum time series (NOAA, 2013a)
[38] Based on NOAA Atlas 14 annual maximum time series (NOAA, 2013a)
[39] The 25-year storm is the design storm for the culvert facility but these values were not generated for the *Climate Variability in Change in Mobile, AL* report (USDOT, 2012) or the *Screening for Vulnerability* report (USDOT, 2014). As a workaround, the 25-year storm values were linearly interpolated from the 20-year and 50-year storm information available from these reports.

Table 6: Equivalent Present Day Return Periods for Projected Future Precipitation Values[40].

Existing NOAA 24-hour Storm Event Return Period	Wetter Narrative			Drier Narrative		
	2010–2039 (year storm)	2040–2069 (year storm)	2070–2099 (year storm)	2010–2039 (year storm)	2040–2069 (year storm)	2070–2099 (year storm)
100-yr storm	325	292	408	47	74	59
50-yr storm	227	201	281	36	55	46
25-yr storm	108	96	137	15	23	19
20-yr storm	87	78	111	12	19	16
10-yr storm	52	46	65	8	12	10
5-yr storm	24	22	29	4	6	5
2-yr storm	4	4	5	1	1	1

[40] Return periods for predicted future precipitation events are based upon current NOAA Atlas 14 return periods and precipitation totals versus the projected future precipitation totals as presented in Table 1.

The "Wetter" narrative uses the outputs of the climate models employed in earlier stages of the Gulf Coast Project to estimate how precipitation patterns might shift with future climate change. In keeping with the definition of this scenario developed in the *Screening for Vulnerability* report, the "Wetter" narrative represents the 95th percentile (mean+1.6 SD[41]) precipitation depths of all the climate model outputs under the range of climate scenarios considered. In other words, 95% of the model outputs across all the emission scenarios and climate models were less than the amounts shown for this scenario; thus, this narrative can be viewed as approaching a reasonable upper boundary for future climate changes. This narrative includes shifting probabilities of projections for three future time periods (2010-2039, 2040-2069, and 2070-2099), indicating the dynamic evolution of climate changes over this century. The values shown in Table 5 were derived by applying the projected changes for the Mobile station, the one nearest the study site, to the observed baseline scenario (described above) for each future time period. Note that the 25-year return period storm was not available directly from the model outputs provided. Instead, the 25-year storm was estimated by linearly interpolating between the model outputs provided for the 20-year and 50-year storms. Note from Table 5 that across all storm events and future time horizons, the projected precipitation amounts exceed the upper 90% confidence interval for the NOAA Atlas 14 data, thus demonstrating significance beyond the current uncertainty in the historical climate record.

The "Drier" narrative is calculated similarly to the "Wetter" narrative except that it represents the 5th percentile (mean-1.6 SD) of precipitation depths. The "Drier" narrative was not considered for testing in the hydraulic analysis of the culvert because precipitation values under this scenario are generally lower or nearly equal to historical values. Lower precipitation values mean lower peak flow rates at the facility; therefore, adaptation measures would not be needed to handle additional flows. The "Drier" narrative will, however, be a consideration in the economic analysis when developing recommendations for adapting this facility, as this scenario has the same likelihood of occurring as the "Wetter" narrative and this needs to be factored into decision-making.

Step 5 –Assess Performance of the Existing Facility

Assessing the performance of a culvert first requires detailed hydrologic and hydraulic modeling of the watershed in the vicinity of the facility to understand expected peak flows. These peak flows can then be used to evaluate the culvert's performance relative to its design standards.

Hydrologic Modeling

Peak flows through the culvert were modeled for various storm events and climate scenarios using the U.S. Department of Agriculture (USDA)-Natural Resources Conservation Service (NRCS) WinTR-20 program.[42] The WinTR-20 program utilizes NRCS hydrologic analysis

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[41] Standard deviations
[42] USDA-NRCS, 2009

methodology to calculate runoff using the following inputs: drainage area, land use, soils, time of concentration,[43] and precipitation.

As previously discussed, the climate inputs for precipitation are limited to a minimum duration of 24-hours, due to limited output options from the available climate models. In consideration of this limitation, the selection of which culvert to study in this project focused on watersheds with a size and time of concentration that fell within a reasonable range of applicability for a 24-hour storm and the TR-20 model. The TR-20 development manual suggests an upper watershed limit of 25 square miles (64.7 square kilometers).[44] As for the lower limit, research results produced by Fennessey, Miller, and Hamlett (2001) suggest that the TR-20 computer model reasonably predicts discharges for urban watersheds down to a 1.2 acre (0.5 hectare) size (20 acre [8.1 hectare] minimum for wooded watersheds).[45] The model documentation for TR-20, does document that the main time increment of the models should be less than 30% of the watershed time of concentration. Since the TR-20 model has a computational limitation of six minutes in the main time increment, this results in a practical lower limit of 18 minutes for the time of concentration. To assess the time of concentration to the Airport Boulevard Culvert, a time of concentration path was developed (see Figure 9). The time of concentration along this path was calculated to be 1.5 hours.[46] Thus, the Montlimar Creek watershed at Airport Boulevard, with a drainage area of 2,137.6 acres / 3.3 square miles (865.1 hectares / 8.7 square kilometers) and a time of concentration calculated to be 1.5 hours, falls within the criterion for use of the TR-20 model with a 24-hour storm duration.

For watershed sizes smaller than the 1.2 acres (0.5 hectares) suggested by Miller and Fennessey's work, additional research will be necessary into precipitation intensity-duration-frequency (IDF) curves for sub-one hour durations with climate change. The climate change IDF curves will allow for the use of common small catchment hydrologic methods, including the Rational Method, to be utilized in these types of analysis.

Analysis of both existing and future land use conditions was necessary to evaluate current flows and predicted future flows at the Airport Boulevard culvert. Derivation of both existing and future land use began with consideration of the City's GIS-based zoning map. Existing land use conditions were developed from the zoning map and aerial photos.[47] Large, easily identifiable areas such as woodlands, golf courses, and lower density residential neighborhoods were located on the aerial photos and compared to the zoned land use. If the actual land use shown on the aerials differed from the zoning, corresponding edits were made to the zoning layer to create a map approximating

[43] Time of concentration is the time needed for water to flow from the most hydrologically remote point of the drainage area to the discharge point of the drainage area.
[44] USDA-SCS, 1992
[45] The study utilized the 24-hour precipitation curves from NOAA's Technical Paper 40.
[46] The time of concentration was calculated using the segmental method.
[47] Detailed current land use data was not made available at the time of initial analysis. This data was received at a later date and a comparison was made between the approach used here and this more detailed data. The comparison showed a less than 5% change in discharges with use of the more detailed data so it was decided to continue using the outputs from the initial approach.

existing land uses (see Figure 15). Future land use conditions for the drainage area were identified from build-out of the zoning layer (see Figure 16). If the tributary area is governed by stormwater management regulations that restrict flow to existing runoff conditions, the full-build-out runoff conditions may not apply, depending upon the effectiveness of the runoff control measures.

Approximately 70% of the drainage area consists of residential neighborhoods, 16% open pervious spaces (mostly comprised of golf courses), 2% woods, and 12% commercial and institutional land uses. In the future, based on build-out of the City's zoning, all of the open pervious spaces are changed to residential uses and there are no wooded areas. Thus, the future land use composition is slated to be 88% residential and 12% commercial and institutional.

The TR-20 model as developed by the NRCS, utilizes curve numbers[48] to represent the hydrologic properties of the watershed. Curve numbers themselves are determined based on the above discussed land uses along with the hydrologic soil group[49] types for the different soil types in the watershed. The hydrologic soils group data was obtained from the USDA-NRCS 2010 Soil Survey Geographic Database for Mobile, AL.[50] As a cautionary note, the analyst and designer must coordinate the datum planes used by the various sources of information to be certain that all elevations are referred to the same bench mark elevation.

[48] Curve numbers are a numeric approximation of a soil and land use combination's ability to produce overland runoff. The numbers range from a high end of 100, where all precipitation will be transferred to overland runoff, to a low end of near zero, which represents a condition where no overland runoff will be created.
[49] Hydrologic soil groups refer to the sorting of commonly occurring soil types into groups of A, B, C, or D dependent on the soil's infiltration and overland runoff performance.
[50] USDA-NRCS, 2010

Figure 15: Existing Land Use Conditions within the Airport Boulevard Culvert Drainage Area[51]

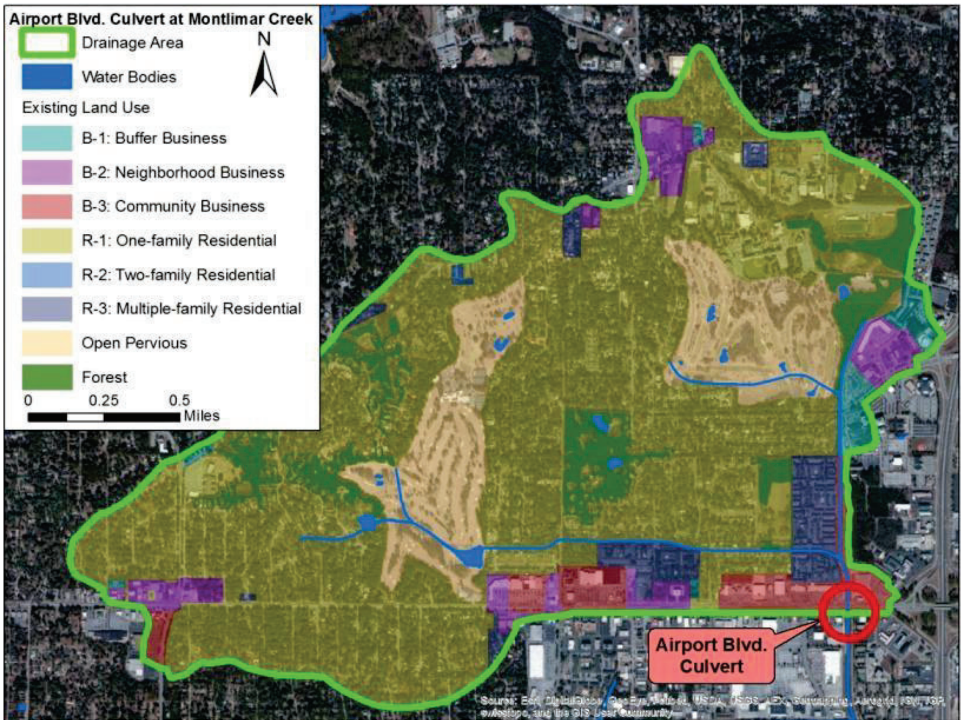
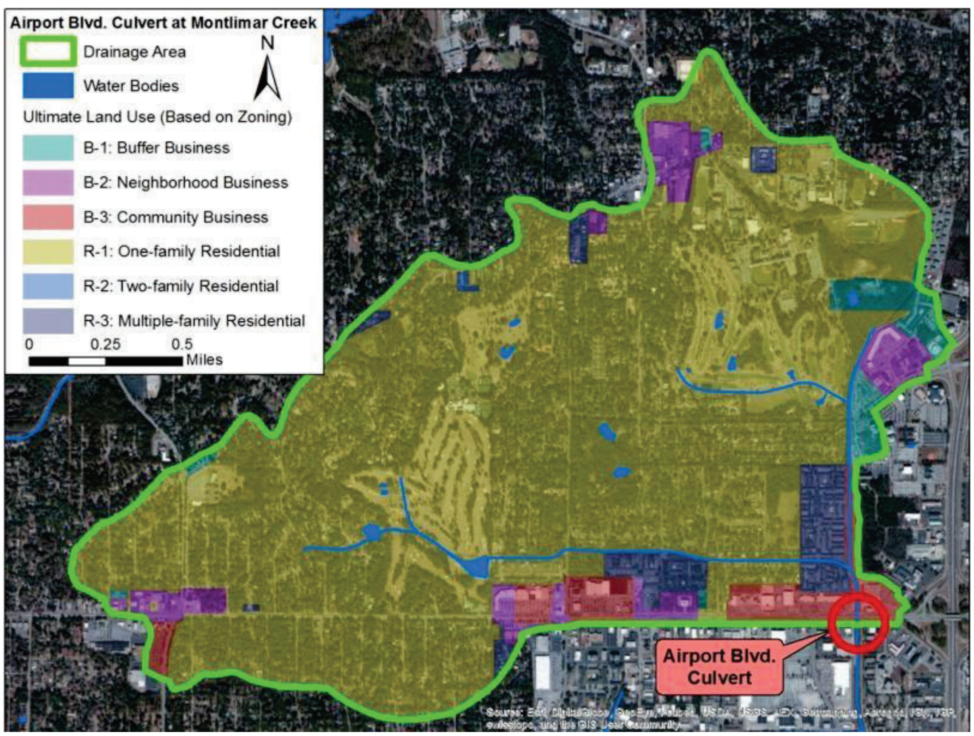


Figure 16: Future Land Use Conditions within the Airport Boulevard Culvert Drainage Area[52]



[51] Source of zoning data: City of Mobile GIS
[52] Source of zoning data: City of Mobile GIS

The hydrologic analysis also considered a range of temporal rainfall distributions for the evaluation of flows at the culvert to determine the appropriate values. Among the rainfall distributions considered were Soil Conservation Service (SCS) Type II and Type III rainfall type curves[53] as well as 24-hr temporal distributions developed by NOAA based on empirical rainfall data collected for the Southeastern Region of the United States. NOAA has developed detailed temporal distributions based on actual gauge data for a range of storm types depending on cumulative percentages of precipitation at various time steps. It was determined that the recently developed (as of June 2013) NOAA distributions for the Southeast region would be the most accurate representation of the storm distributions in the Mobile area.

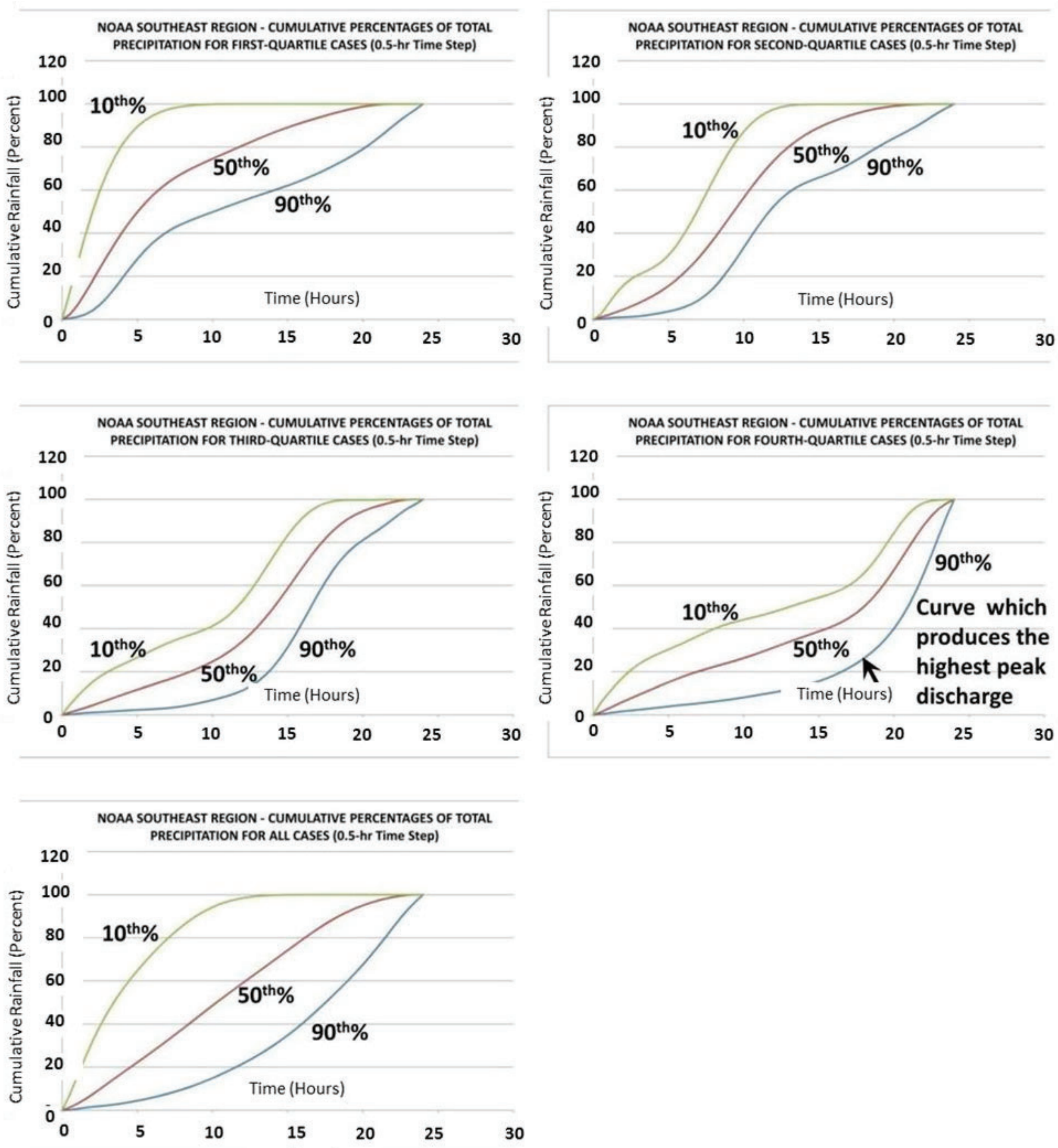
The NOAA temporal distributions used in this study were for the 24-hour duration storm. Separate temporal distributions were developed by NOAA for four precipitation cases defined by the time during the storm (first, second, third, and fourth quarters) in which the greatest percentage of the total precipitation occurred. For example, for 24-hour duration storms, the first quartile case refers to storm events where the largest amount of rain fell within the first six hours of the duration, the second quartile in the second six hours, and so on. Figure 17 shows graphical plots of the NOAA temporal distributions that were considered: the 10^{th} to 90^{th} percentile of first-, second-, third-, and fourth-quartile cases, as well as the overall case. For this analysis, the NOAA rainfall distribution that produced the greatest peak discharge (the 90^{th} percentile of the fourth-quartile case) at the model output was chosen. This distribution was chosen because it validated well against regional regressions curves (discussed below), whereas more moderate distributions did not validate well. This distribution was also used for the future scenarios because it is the most extreme distribution that current climate shows is possible in the region.

Peak flows through the Airport Boulevard culvert were determined for the two-, five-, 10-, 20-, 25-, 50-, and 100-yr storm events under various climate scenarios. The Observed precipitation depths were run utilizing both existing and future land use conditions, while the NOAA 90% Upper Confidence Limit, "Wetter" narrative, and "Drier" narrative scenarios utilized future land use conditions.

A comparison was performed between the existing condition TR-20 model discharges and the regional regression estimates for urban streams in Alabama,[54] an alternative approach to estimating flows developed by USGS, to validate the model conditions. These regional regression curves are applicable to urban areas statewide with drainage areas between one and 43 square miles. An exception includes regions with impervious chalk and marl which does not pertain to the Mobile area. The use of these equations is therefore recommended for the Mobile area.

[53] USDA-SCS, 1986
[54] USGS, 2007

Figure 17: NOAA Atlas 14 Temporal Rainfall Distributions for the Southeast Region[55]



55 NOAA, 2013b

The two-year discharge fell within the regression estimate and the lower standard error of prediction, while the higher storm event discharges fell within the regression estimate and the upper standard error of prediction. The regression equations were utilized as a basis for calibration / validation of the TR-20 model. Since the regression equations are empirically derived and regionally specific, they provide a reasonable basis for calibration of the theoretical model. In the theoretical model, the resultant discharges can be highly influenced by development factors such as channel 'n' values,[56] sheet flow lengths, and precipitation temporal distributions that can be somewhat arbitrarily chosen. For a basis of comparison, the first cut uncalibrated existing condition TR-20 model produced a 100-year storm in excess of 10,000 cubic feet per second (283.2 cubic meters per second), while once calibrated against the regional regression, this value dropped to 4,300 cubic feet per second (121.8 cubic meters per second).

Table 7 shows the existing condition TR-20 model peak discharges compared to the USGS regional regression peak discharge estimates and the discharges with lower and upper standard error. This table also shows a comparison to the peak discharges presented in the FEMA flood insurance study for Mobile County[57] for a location on Montlimar Creek just downstream of Airport Boulevard. The FEMA discharges were calculated based on regression equations presented in USGS (1985) and USGS (1974). These discharges are provided for a point of comparison and were not used for calibration because the methods predate the USGS regression equations (2003) described above. Table 8 shows the final model outputs comparing current peak flows to projected future peak flows.

[56] Manning's 'n' value is a frictional resistance factor that approximates the effects of various channel and floodplain conditions on the conveyance rate of flows. An increase in this n value will cause a decrease in the velocity of water flowing across a surface.
[57] FEMA, 2010d

Table 7: TR-20 Peak Flows Compared to Regional Regression Peak Flow Estimates at the Airport Boulevard Culvert

24-hour Storm Event Return Period	TR-20 Observed 1980–2009 w/ Current LU (cfs)	FEMA Flood Insurance Study Estimate (cfs) 2010	Regional Regression Estimate (cfs)	Regional Regression Estimate at Lower Standard Error (cfs)	Regional Regression Estimate at Upper Standard Error (cfs)
100-yr storm	4,361.8	3,260	3,601.7	2,521.2	4,682.2
50-yr storm	3,975.0	2,900	3,204.7	2,371.5	4,037.9
25-yr storm	3,045.1*	Unavailable	2,816.7	2,140.7	3,492.8
20-yr storm	2,813.4	Unavailable	Unavailable	Unavailable	Unavailable
10-yr storm	2,424.8	2,090	2,298.6	1,815.9	2,781.3
5-yr storm	1,889.0	Unavailable	1,857.2	1,467.2	2,247.2
2-yr storm	1,030.8	Unavailable	1,222.3	904.5	1,540.2

* Asterisks denote flows derived from interpolated precipitation values

Table 8: TR-20 Projected Peak Flows at the Airport Boulevard Culvert

24-hour Storm Event Return Period	Observed 1980–2009 w/ Current LU (cfs)	Observed 1980–2009 w/ Future LU (cfs)	NOAA 90% Upper Conf. Limit w/ Future LU (cfs)	"Wetter" Narrative w/ Future LU			"Drier" Narrative w/ Future LU		
				2010–2039 (cfs)	2040–2069 (cfs)	2070–2099 (cfs)	2010–2039 (cfs)	2040–2069 (cfs)	2070–2099 (cfs)
100-yr storm	4,361.8	4,484.6	6,553.8	7,347.1	7,122.3	7,844.8	4,137.9	4,754.8	4,445.1
50-yr storm	3,975.0	4,097.9	5,404.3	6,626.9	6,396.8	7,047.2	3,789.3	4,330.8	4,097.9
25-yr storm	3,045.1*	3,170.4*	4,445.1	5,328.1*	5,138.7*	5,712.9*	2,899.1*	3,325.2*	3,131.6*
20-yr storm	2,813.4	2,938.1	Unavailable	4,984.9	4,831.7	5,369.3	2,664.8	3,092.6	2,899.1
10-yr storm	2,424.8	2,549.4	3,170.4	4,253.3	4,097.9	4,560.1	2,316.6	2,664.8	2,510.5
5-yr storm	1,889.0	2,008.1	2,467.1	3,325.2	3,247.6	3,557.5	1,817.4	2,086.9	1,968.4
2-yr storm	1,030.8	1,134.6	1,665.5	1,855.0	1,855.0	2,008.1	987.7	1,134.6	1,061.0

* Asterisks denote flows derived from interpolated precipitation values

Hydraulic Modeling and Performance of the Existing Culvert

Hydraulic culvert analyses were conducted to evaluate the performance of the Airport Boulevard culvert under current and future peak flows. The Federal Highway Administration's (FHWA) HY-8 Version 7.2 program was used for these purposes.[58] The culvert computations considered the discharge; culvert size, slope, and material; roadway data; and channel characteristics. The roadway profile data was obtained from a 1961 design plan for the resurfacing of Airport Boulevard.

One uncertainty of the hydraulic model was that the slope of the culvert was not available: as a workaround, it was estimated to be approximately 1% based on two foot (0.6 meter) LIDAR contours. To be specific, the contour elevation was 26 feet (7.3 meters) at the upstream end of the culvert and 24 feet (6.7 meters) at the downstream end (see Figure 11): based on the vertical difference of two feet (0.6 meters) and the culvert length of 200 feet (61.0 meters), the slope was determined to be 1%. Barrel slope is critical to the hydraulic analysis of a culvert so, to ensure the 1% estimate was reasonable, a sensitivity analysis was performed by running the HY-8 program using 0.5% and 1.5% culvert slopes as well. This was achieved by holding the inlet elevation constant while raising and lowering the outlet elevation by one foot (0.3 meters) in the model. Results showed that the headwater elevations[59] were the same for all three slopes for discharges less than or equal to 8,000 cubic feet per second (226.5 cubic meters per second). Headwater elevations only began diverging for discharges beyond this value, which is higher than the discharge calculated for the 100-year "Wetter" narrative end-of-century storm event. Although a reasonable estimate of the culvert slope was used in this analysis, an actual project would require field surveys of the site to gather more accurate information.

Another uncertainty was the exact height of the roadway above the invert (bottom) of the culvert. The 1961 design plan provided the roadway elevation but not the culvert invert elevation. However, a close approximation of 26 feet (7.9 meters) for the invert elevation was obtained based on LIDAR contours, culvert size, slab thickness, and fill depth. The peak flows developed through the hydrologic analysis were analyzed with the culvert model to determine the headwater elevation at the culvert for various climate scenarios.

The tailwater conditions at the culvert location are also a potential point of uncertainty in the analysis. As discussed, the modeling procedure used HY-8 with tailwater values based upon normal depth and channel slope. The potential exists for downstream structures to influence this backwater elevation or for other floodplain limiting factors to control the tailwater elevation. The detailed evaluation of any structure for replacement should include a hydraulic study that fully considers downstream and upstream channel hydraulic characteristics and the impacts of other

[58] FHWA, 2012b
[59] Headwater elevation is the level of water immediately upstream of the inlet (upstream end) of a culvert or any other conduit.

factors into the hydraulics of a particular site, however, this level of detail was outside of the scope of this current study.

Culvert performance was assessed according to Alabama Department of Transportation (ALDOT) standards, which have been adopted by the City of Mobile. Per the 2008 *ALDOT Bridge Bureau Structures Design and Detail Manual*,[60] the 25-year flood is to be used for design of waterway crossings on secondary routes such as Airport Boulevard. A minimum of two feet (0.6 meters) of freeboard[61] is required above the design flood stage (relative to the edge of pavement) to keep the water surface an adequate depth below the pavement base. As such, the 25-year storm peak flows for various climate scenarios were analyzed through the hydraulic model and adaptation options were developed based on a two foot (0.6 meter) freeboard requirement.

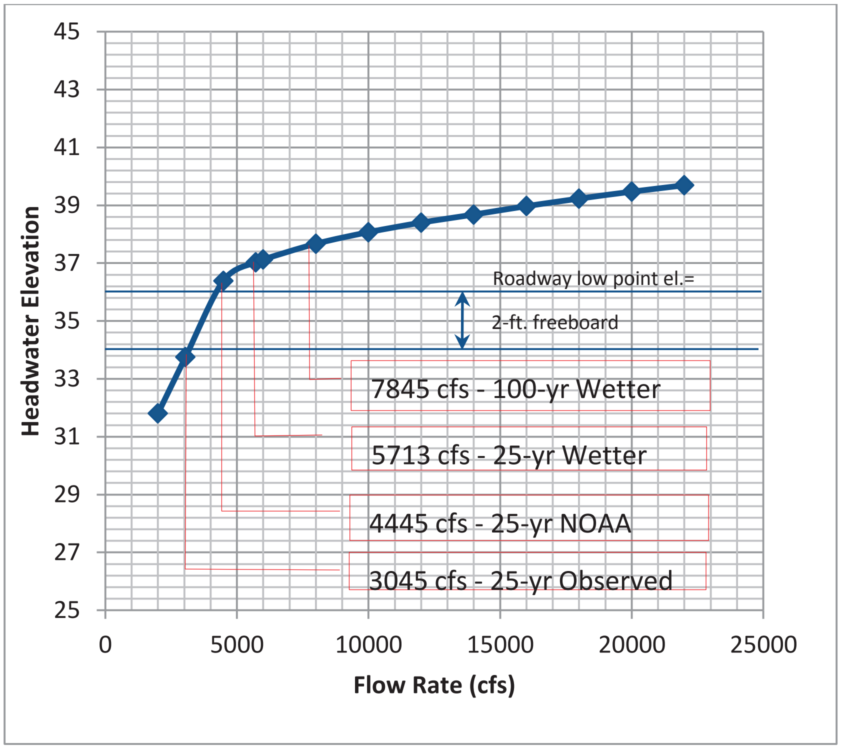
The 25-year storm peak flows for the Observed precipitation depths, the NOAA 90% Upper Confidence Limit, and "Wetter" narrative (end-of-century, 2070-2099 time period) scenarios were analyzed with the culvert model. The results, shown in Table 9, indicate that under existing precipitation and land use conditions, the current culvert meets ALDOT standards. The culvert also performs to standard with Observed precipitation amounts and future land use. However, the standard is not met for the other two scenarios tested. In the NOAA 90% Upper Confidence Limit scenario, the 25-yr flood stage overtops the low point of the roadway by 0.4 feet (0.1 meters) and in the "Wetter" narrative (end-of-century, 2070-2099 time period) the 25-yr flood stage overtops the low point of the roadway by one foot (0.3 meters). Figure 18 illustrates this information graphically.

Table 9: Airport Boulevard Culvert Modeled Performance under Various Climate Change Scenarios

	Observed 1980-2009 w/ Current LU	Observed 1980-2009 w/ Future LU	NOAA 90% Upper Confidence Limit w/ Future LU	"Wetter" Narrative End-of-century (2070–2099) w/ Future LU
Roadway Low Point Elevation (ft.)[62]	36.0	36.0	36.0	36.0
25-yr Flood Stage (ft.)	33.8	34.0	36.4	37.0

[60] ALDOT, 2008
[61] Freeboard is the excess height between a specific design water surface elevation and a given point of reference (e.g., roadway shoulder, low chord of a bridge, or crown of a culvert).
[62] The low point is located immediately to the east of the culvert location.

Figure 18: Existing Airport Boulevard Culvert Stage[63]-Discharge Curve

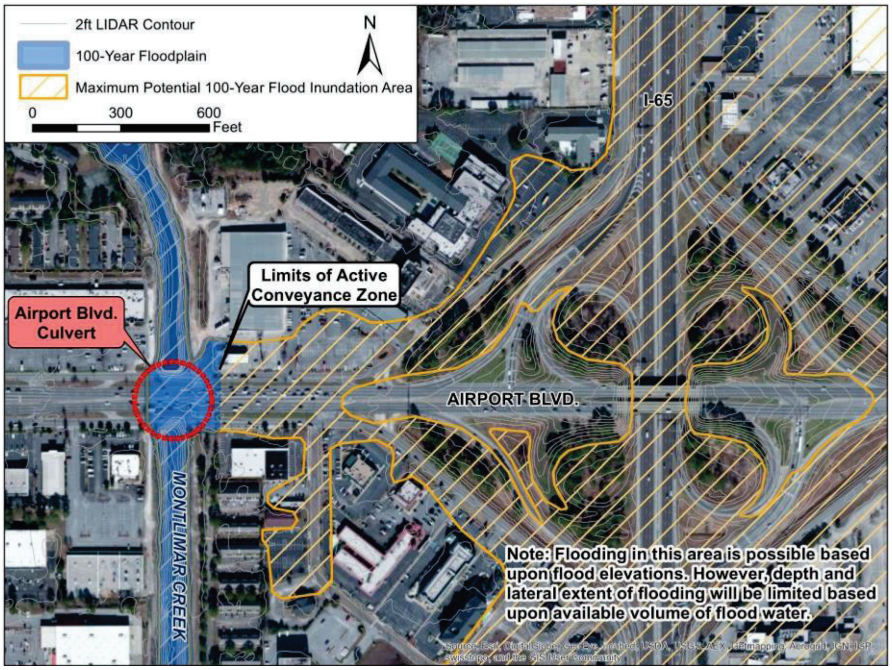


Flooding impacts on surrounding areas were evaluated based on the performance of the existing four cell box culvert. The degree of flooding was analyzed for the 100-year storm event under three scenarios: Observed conditions, the NOAA 90% Upper Confidence Limit, and “Wetter” narrative (end-of-century, 2070-2099 time period) scenarios. Figure 19, Figure 20, and Figure 21 show the potential inundation areas for each of the three scenarios. The areas shown are projected to be subject to inundation due to flood water overtopping the stream channel banks and the Airport Boulevard culvert. The lateral extent of the inundation areas are approximated based on the headwater elevation, noted in the figure footnotes, produced by the hydraulic model for each of the three scenarios. The area shaded in blue denotes the predicted floodplain limits adjacent to the flooding source. The potential floodplain is truncated at the limits of the active conveyance zone east of the culvert. The limits of the active conveyance zone as noted on the figures were delineated based upon a local ridgeline that is overtopped by the storm events. This limit is approximate and would require detailed 2-dimensional modeling to define in greater detail. The area beyond the limits of the active conveyance zone, shown by the hatching, represents the theoretical maximum area that may be vulnerable to inundation based upon the computed floodwater elevation relative to the ground topography. While the topographic contours show a clear flow path from the conveyance zone to this low-lying area, the depth and lateral extent of flooding in this area will be limited based upon the available volume of flood water from Montlimar Creek. A detailed two-dimensional unsteady flow analysis, beyond the

[63] Stage refers to water elevation.

scope of this case study, would be required to determine the volume of flood water that would flow eastward, the likely flow paths of that water, and, given these considerations, how much of the land to the east would actually become inundated.

Figure 19: Potential 100-year Inundation Area with Observed Precipitation Depths, Current Land Use, and the Existing Airport Boulevard Culvert[64]



[64] The headwater elevation of this scenario is 36.3 feet (11.1 meters). Note: Although the flood boundaries overlap nearby buildings on the map, the roofs are not overtopped by the 100-year flood event.

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Figure 20: Potential 100-year Inundation Area under NOAA 90% Upper Confidence Limit Scenario with Future Land Use and Existing Airport Boulevard Culvert[65]

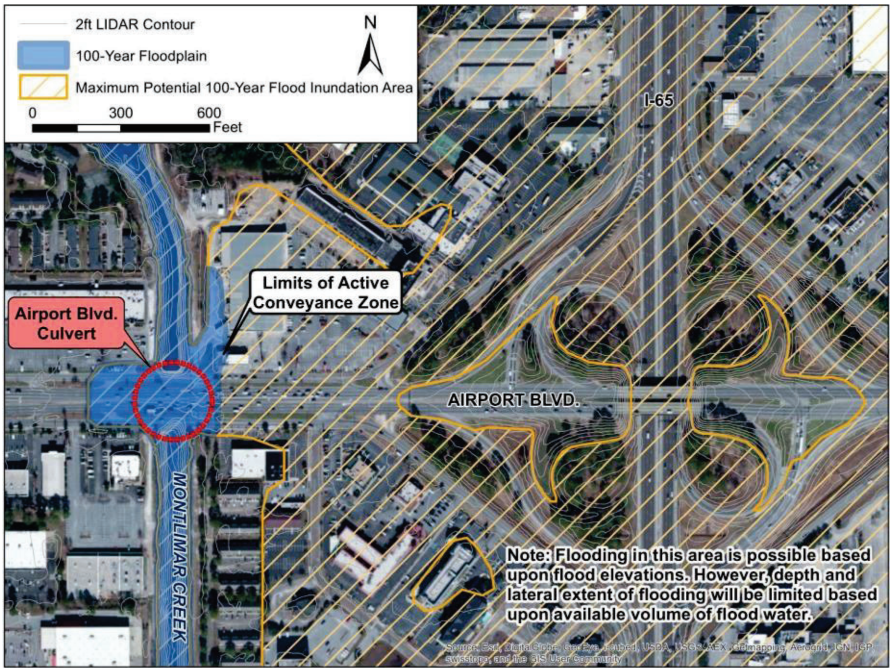
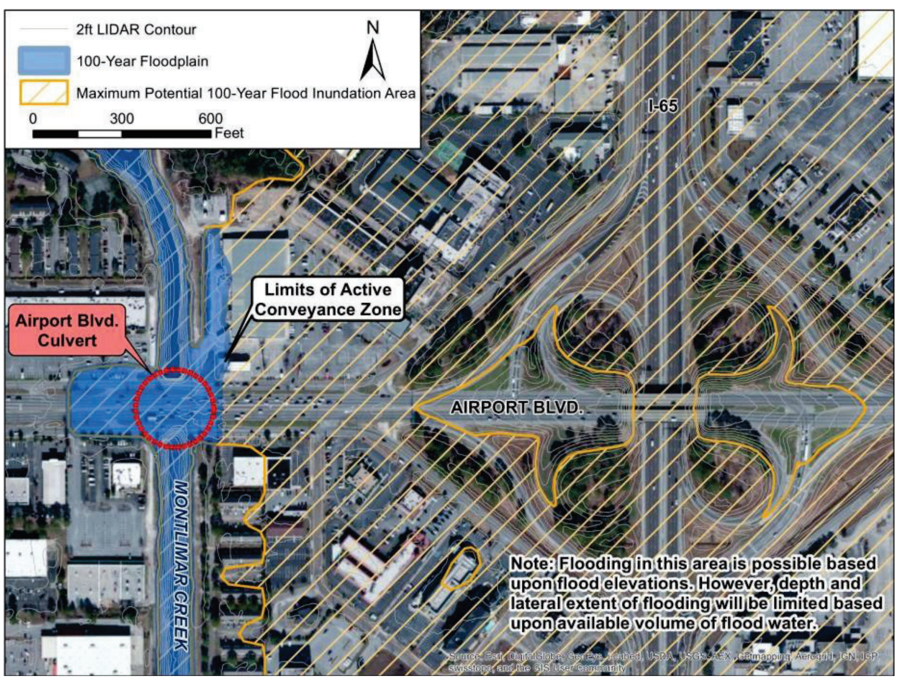


Figure 21: Potential 100-year Inundation Area under "Wetter" Narrative (End-of-Century, 2070–2099 Time Period) with Future Land Use and Existing Airport Boulevard Culvert[66]



[65] The headwater elevation of this scenario is 37.3 feet (11.4 meters). Note: Although the flood boundaries overlap nearby buildings on the map, the roofs are not overtopped by the 100-year flood event.
[66] The headwater elevation of this scenario is 37.6 feet (11.5 meters). Note: Although the flood boundaries overlap nearby buildings on the map, the roofs are not overtopped by the 100-year flood event.

Step 6 – Identify Adaptation Option(s)

The alternatives for adaption to meet design standards include expanding the existing crossing or controlling the runoff that reaches the crossing. The alternatives considered and their pros and cons are presented in Table 10. Expanding the capacity of the existing crossing is the most direct solution; however, it could have a negative effect downstream by increasing the flow rate, stage (water elevation), and downstream erosion because the existing culvert acts to attenuate the flow. The latter approach, controlling the runoff that reaches the crossing, would mitigate these affects and not require modification of the crossing. This approach, although not considered here due to this study's site-specific focus, is worthy of additional investigation. Such an approach would require a regional drainage plan with up-stream retention or detention facilities, potential condemnation of property, and possible zoning or development regulation changes.

To demonstrate how an adaptation analysis could proceed, this analysis focuses on the approach of increasing the capacity of the culvert crossing. In actual practice, the effects downstream mentioned above would be assessed to determine the impacts and the costs associated with them that the project would have to bear. As mentioned previously, the drainage system (upstream and downstream of the culvert) and its effect on culvert operations should be considered in an actual case. For example, widening the stream at the culvert entrance could result in sediment deposits because of lower flow velocity. This effect can require that inspection and maintenance be increased because the sediment accumulation would reduce culvert capacity. The idea of a bridge replacing the culvert was briefly considered but ruled out because the low allowable headwater height would not allow an adequate structure depth without major roadway reconstruction to raise its elevation.

Table 10: Adaptation Design Options Considered for the Airport Boulevard Culvert

Possible Alternatives	Description	Pros	Cons
Regional Drainage Area Management	• Perform drainage area analysis to determine best management procedures • Consider restrictions or constraints for future development • Acquire RW for and construct one or more detention / retention facilities to attenuate runoff AND volume to existing downstream capacity	• Reduces runoff rate and volume to existing values for selected design storm runoff at roadway crossing and farther downstream • No traffic delay on Airport Boulevard	• Large project undertaking compared to the culvert option • Possible zoning changes required that would restrict development (potential inverse condemnation) • Acquisition of large amounts of property required for facilities • Large capital and maintenance costs • Lengthy project development time
Bridge	• Replace culvert with a single-span bridge	• Increases crossing capacity • Increases hydraulic opening / decreases flow obstructions. • Provides increased protection to surrounding properties for existing and future runoff amounts	• Large project undertaking compared to the culvert option • Structure depth requires raising the roadway for a horizontal distance of about 600 feet (182.9 meters) on each side of the culvert • Long period of traffic disruption • Increases flow rate and volume downstream • Large capital and maintenance cost

Possible Alternatives	Description	Pros	Cons
Culvert Modification (Option One)	• Add one cell on each side of the existing crossing	• Increases crossing capacity • Headwater elevation meets criteria for the 25-year NOAA rainfall value • Provides increased protection to surrounding properties for existing and future runoff amounts • Keeps within the existing easement and right-of-way • Uses the existing facility (sustainable) • Smallest footprint • Lowest capital cost alternative • Shortest project development time	• Disrupts traffic • Increases flow rate and volume downstream • Increased potential for sediment aggradation / increased maintenance needs.
Culvert Modification (Option Two)	• Replace the existing crossing with largest crossing that will fit within the space available	• Increases crossing capacity • Keeps the 100-year "Wetter" narrative precipitation runoff at the edge of pavement—not overtopping the roadway • Provides increased protection benefit to surrounding properties for existing and future runoff amounts over Option One	• Longer period of traffic disruption than Option One • Increases flow rate and volume downstream more than Option One • Higher capital cost than Option One • Increased potential for sediment aggradation / increased maintenance needs

Other factors that may complicate the development of adaptation options are any pipes that are located near the culvert or discharge into it. At this study site, a 48 inch (121.9 centimeter) bituminous coated concrete drainage pipe and a 15 inch (38.1 centimeter) reinforced concrete drainage pipe discharge into the westernmost barrel of the culvert. A pressured water line may also be crossing the culvert. Although it was not evaluated in this study, adaptation solutions must take into account potential impacts to nearby pipes and utilities which may need to be relocated, modified, or temporarily taken offline to carry out the project.

With these limitations in mind, the selection of alternatives is based on the following guidelines:

- Keeping the solution within the existing easement and right-of-way to the extent practical
- Making use of the existing facilities to the extent practical
- Keeping the footprint of the alternative as small as practical

Plotting stage-discharge curves developed from the hydrologic and hydraulic models of various types of crossings helps visualize the actual performance against the design standard. For this project, we considered eight combinations of culvert cell sizes. Based on the guidelines above, we selected the narrowest combination with the lowest rise. Two levels of adaptation options are suggested for the Airport Boulevard culvert: one that is optimized for the NOAA 90% Upper Confidence Limit and a second that is optimized for the “Wetter” narrative (end-of-century, 2070-2099 time period). The goal of both adaptation options is to achieve the minimum two feet (0.6 meters) of freeboard from the 25-year flood stage to the edge of pavement at the low point of the roadway. Both adaptation options involve the addition of box culvert cells or expansion / replacement of existing box culverts in order to increase flow capacity.

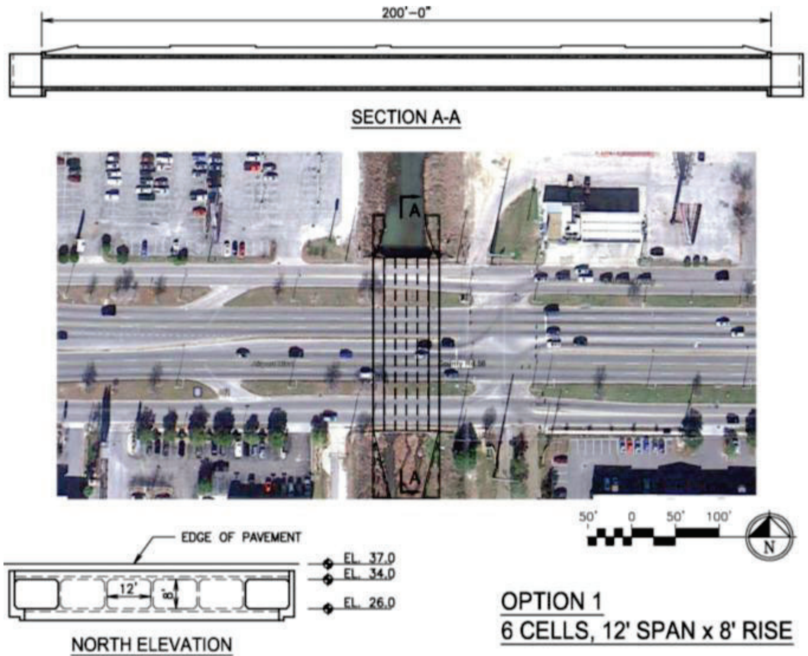
Option One

Option One meets the criteria for the Observed precipitation depths and the NOAA 90% Upper Confidence Limit scenario. It consists of adding one additional 12 foot (3.7 meter) span by eight foot (2.4 meter) rise box culvert on each side of the existing four cells of the same size. Transitioning the channel width to the wider entrance and from the wider exit will require concrete training walls. Figure 22 shows this configuration.

The work, estimated to cost $1.7 million, includes:

- Removing the existing wing walls on both sides (to stay within the right-of-way and minimize channel alignment changes)
- Excavating and installing one box culvert on each side of the existing crossing
- New headwall extensions
- New training walls
- Utility relocation (existing utilities appear to cross and run parallel and close to the existing crossing). The estimate includes a “plug number” for these relocations because they have not been identified and located in the field.

Figure 22: Plan for Adaptation Option One of the Airport Boulevard Culvert over Montlimar Creek



Option Two

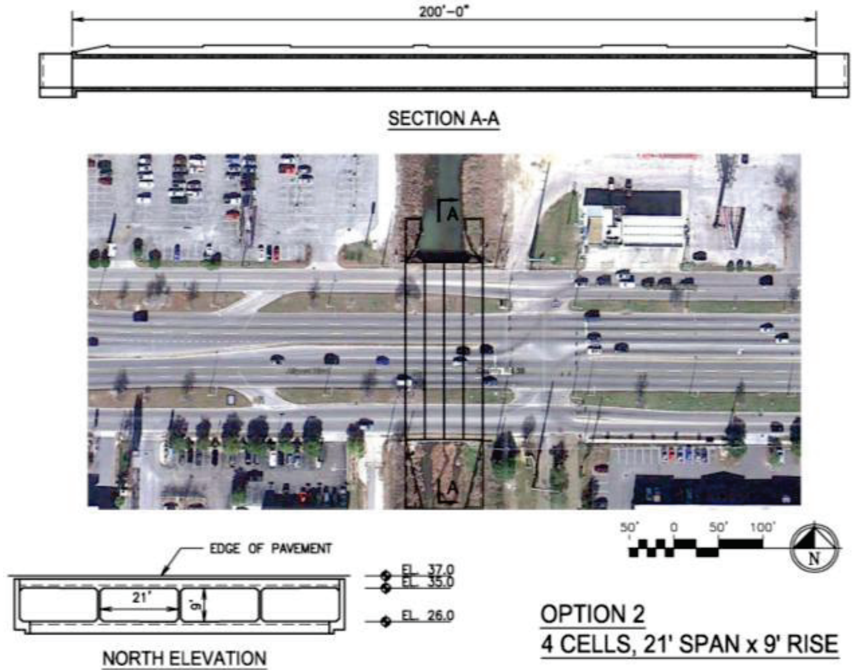
Option One meets the criteria for the Observed precipitation depths and the NOAA 90% Upper Confidence Limit scenario but not the higher flow of the 25-year "Wetter" narrative (end-of-century, 2070-2099 time period). Thus, the project team developed Option Two to address the possibility of the 25-year "Wetter" narrative occurring. This option is within practical limits of the aforementioned criteria, is about 2.4 inches (6.1 centimeters) above the design headwater elevation, and has the benefit of keeping the 100-year "Wetter" narrative runoff to below the elevation of the low point in the roadway so that it does not overtop the road. Option Two consists of removing the existing crossing and installing four cells, each with a 21 foot (6.4 meter) span by nine foot (2.7 meter) rise. Pre-cast spans this wide are available and alternatively could be cast in place which would increase construction duration. The spans would be designed to meet highway loadings as described in the AASHTO standards. The option of raising the culvert height by one foot (0.3 meters) was considered because the required expansion of culvert width is limited by channel width. Transitioning the channel width to the wider entrance and from the wider exit will require concrete training walls. Figure 23 shows this configuration. Widening the channel may increase sediment deposition which would require inspection and sediment removal. Sediment transport was not included in this analysis. An estimate of annual maintenance costs was carried forward in the economic analysis.

The work, estimated to cost $2.5 million, includes:

- Removing the existing culvert and wing walls
- Excavating and installing a culvert with four 21 foot (6.4 meter) by nine foot (2.7 meter) cells

- New headwall extensions
- New training walls
- Utility relocation (existing utilities appear to cross and run parallel and close to the existing crossing). The estimate includes a "plug number" for these relocations because they have not been identified and located in the field.

Figure 23: Plan for Adaptation Option Two of the Airport Boulevard Culvert over Montlimar Creek



Step 7 –Assess Performance of the Adaptation Option(s)

The degree of flooding was analyzed for each adaptive design option using the 100-yr storm event with the Observed precipitation depths and the NOAA 90% Upper Confidence Limit and "Wetter" narrative (end-of-century, 2070-2099 time period) scenarios. As shown on the following curves in Figure 24 and Figure 25, the ALDOT standard is met in Option One for the Observed precipitation depths and the NOAA 90% Upper Confidence Limit scenario and nearly met (within the margin of error) by Option Two for all three cases. Also, note that the 100-year "Wetter" narrative flood elevation exceeds the roadway low point elevation of Option One by one foot (0.3 meters) while it stays approximately at the Airport Boulevard road surface low point elevation under Option Two.

As an additional consideration, potential downstream impacts should be taken into account in the evaluation of adaptation alternatives. For example, the adaptation options propose a wider channel width at the culvert which would need to transition back to the existing channel width downstream. Although it was not conducted for this study, one may evaluate the impacts of the channel width transition on downstream water surface elevations. A U.S. Army Corp of

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Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS) model can be developed to determine if the discharges from the larger magnitude storms may overtop the existing 40 foot (12.2 meter) wide channel downstream. The results of this analysis may show that certain adaptation options are more suitable than others.

Figure 24: Airport Boulevard Culvert Adaptation Option One Stage-Discharge Curve

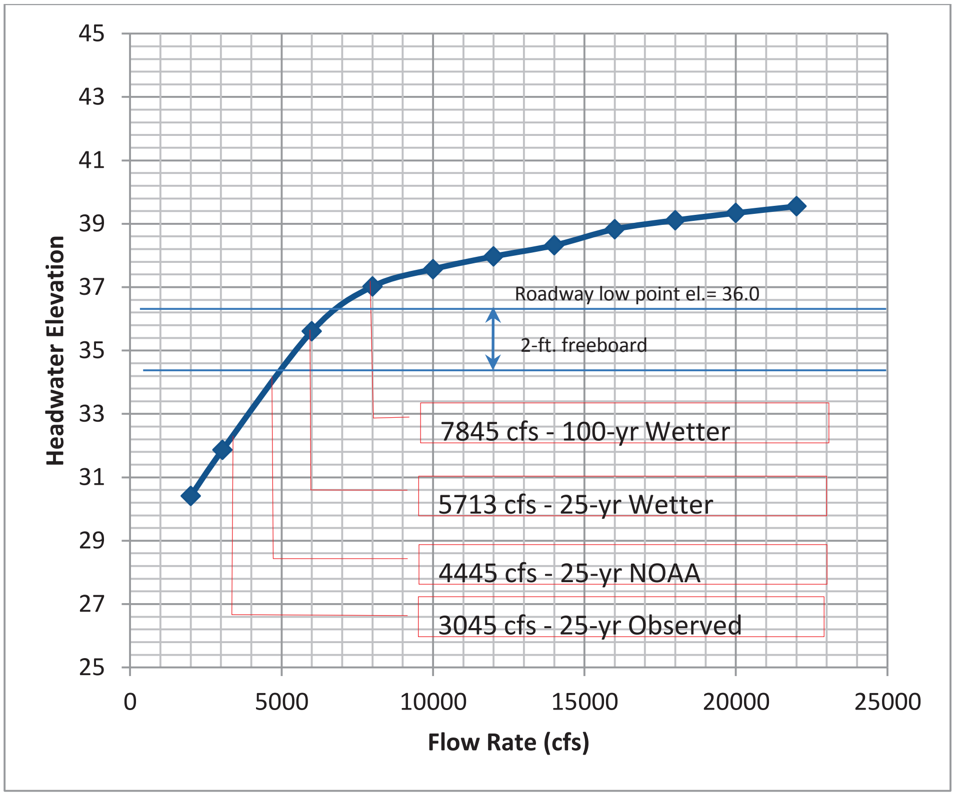
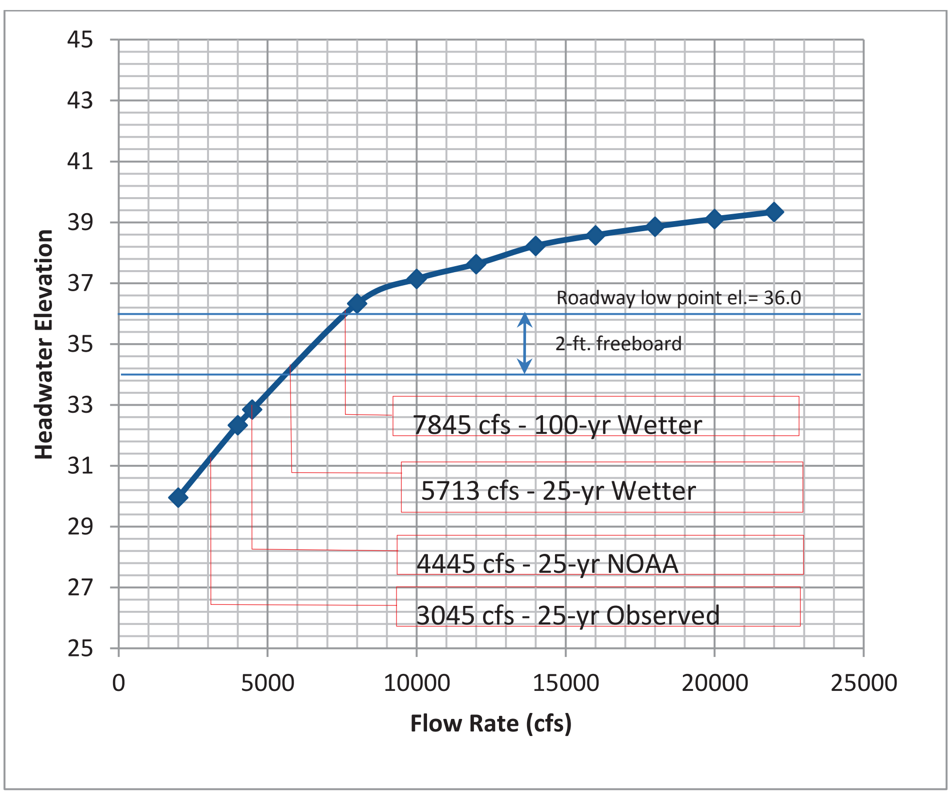


Figure 25: Airport Boulevard Culvert Option Two Stage Discharge Curve



Step 8 –Conduct an Economic Analysis

This step involves an economic analysis of the various adaptation options to aid in the selection of the most cost-effective adaptation measure. The section begins with an overview of the approach taken and the analysis results before proceeding to discuss the entire process in full detail.

<u>Overview</u>

A key feature of climate change is uncertainty. In particular, the timing, severity and frequency of future weather and climate events are not known with any degree of precision. Economic analyses provide valuable information for decision-making where there is a high degree of uncertainty about the future. The benefit-cost analysis model developed for this study uses a probabilistic framework to account for this uncertainty by testing thousands of different combinations of future storm events, each with its own peak discharge flow.

As in any economic study, the level of detail and rigor of the economic analysis should be commensurate to the scale of the project being studied. For climate change analyses, the consequences of that facility's failure should be considered as well when determining the level of effort to expend. The analytical framework used in this study employs Monte Carlo analysis[67] to simulate thousands of different combinations of storm events under five climate / land-use scenarios and then estimates the resultant flooding costs over a 30-year appraisal period. This type of economic analysis may involve a larger level of effort than is required for most culverts, especially smaller culverts, however, it is used in this case study as an illustration of an approach to benefit-cost analysis that can be used to aid in decision-making for a variety of facility types, including those with higher values.

In this analysis, three alternative courses of action are compared:

- **Base Case**: "Do Nothing", leaving the existing culvert as is
- **Option One**: Provision of additional cells adjacent to the existing culvert

[67] Monte Carlo analysis is a computerized mathematical technique widely used in industry to analyze problems where there is inherent uncertainty in predicting future events. It particularly useful when there are large numbers of input variables and hence many degrees of freedom affecting the outcome. Its origins lie with the Manhattan Project: 'Monte Carlo' was a code name coined by one of the lead scientists whose uncle had a penchant for gambling at the casinos in Monaco. Since the end of the war, the technique has been adopted within financial, insurance, oil and gas, and many other industries to assist with their decision-making processes. Despite the connotation of the name, the technique is not completely random; inputs to the models are sampled from pre-determined probability distributions. These inputs are substituted into the model, the output calculated, and the result saved. The process is then repeated using a different set of sampled inputs. Depending upon the number of uncertain variables, a simulation could involve thousands or tens of thousands of recalculations before it is complete. At the end of the simulation, the outputs are collated and analyzed and a probability distribution is generated showing the range of all possible outcomes and the likelihood that they will occur. Monte Carlo simulation is frequently used for applications such as analyzing extreme weather and natural disaster events. Whilst this may appear to be an advanced technique, software packages such as *@Risk* and *Crystal Ball* are widely available as 'plug-ins' to Microsoft Excel at prices which would be affordable to most local and state government agencies. The *@Risk* software tool has been used for this study.

- **Option Two:** Replacing the existing culvert with a new facility that has larger capacity cells. Option Two offers a higher level of protection to Option One as it can accommodate higher discharge flows through the culvert, but is around $800,000 more expensive.

The Monte Carlo approach employed in this case study calculates economic benefits (in terms of avoided flood costs) for Option One and Two relative to the base case using the precipitation depths and resulting flow of the Observed scenario. Discounted cash-flow analysis is then used to rank and select a preferred adaptation option for the culvert upgrade, by comparing the discounted economic benefits against the upfront capital cost of the two upgrade options. After all iterations of the Monte Carlo simulation have run, a probabilistic distribution of results is then generated.

In this analysis, the economic benefits comprise avoided traffic congestion costs resulting from Airport Boulevard and the adjacent I-65 freeway being closed due to flooding.[68] A second analysis was conducted where avoided flood damages to nearby buildings (from flooding attributable to the culvert) were included as benefits as well. These results are presented separately as a sensitivity test given the uncertainties of how much flooding will occur to the east of the site pending further detailed hydrological analysis. It should be noted that anticipated clean-up and repair costs from flood damage to the facility should also be considered in benefit-cost analyses, however, in this case it was assumed that such costs would be minimal given the relatively slow velocities of water at the site.

A summary of the results of the analysis (not inclusive of property damage costs) is shown in Table 11. This table shows the 90th percentile results (out of 1,000 iterations of the Monte Carlo simulation) along with the average economic benefits, Net Present Value (NPV), and Benefit-Cost Ratio (BCR) of all five climate scenarios. The range of benefits, NPVs, and BCRs across the five scenarios is provided in parentheses. The results show that whilst both options are economically viable, Option One is preferred as it has the higher BCR of the two options at 3.5.

Approach

There is considerable uncertainty when appraising climate change initiatives in that the timing, severity, and frequency of future weather and climate events are not known with any degree of precision. If scarce public funds are invested in infrastructure adapting to climate change and no weather events occur in the near-term, then the infrastructure adaptations will, in essence, "lie idle" and the funds could have been used for alternate more immediate needs. Conversely, if infrastructure investments are delayed but a number of significant flooding events occur, then widespread economic damage that could otherwise have been avoided will result.

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[68] Although there are uncertainties in the location and amount of flooding expected to the east of the Airport Boulevard culvert due to spill over attributable to the culvert, a conservative assumption was made that I-65 would be affected by the resulting flooding. An initial evaluation of likely flow paths showed that much of the overflowing water from Montlimar Creek would likely pass through the drainage infrastructure of the I-65 interchange with Airport Blvd. and this infrastructure is known to have capacity challenges. However, further detailed hydrological analysis, beyond the scope of this case study, would be required to verify this assumption.

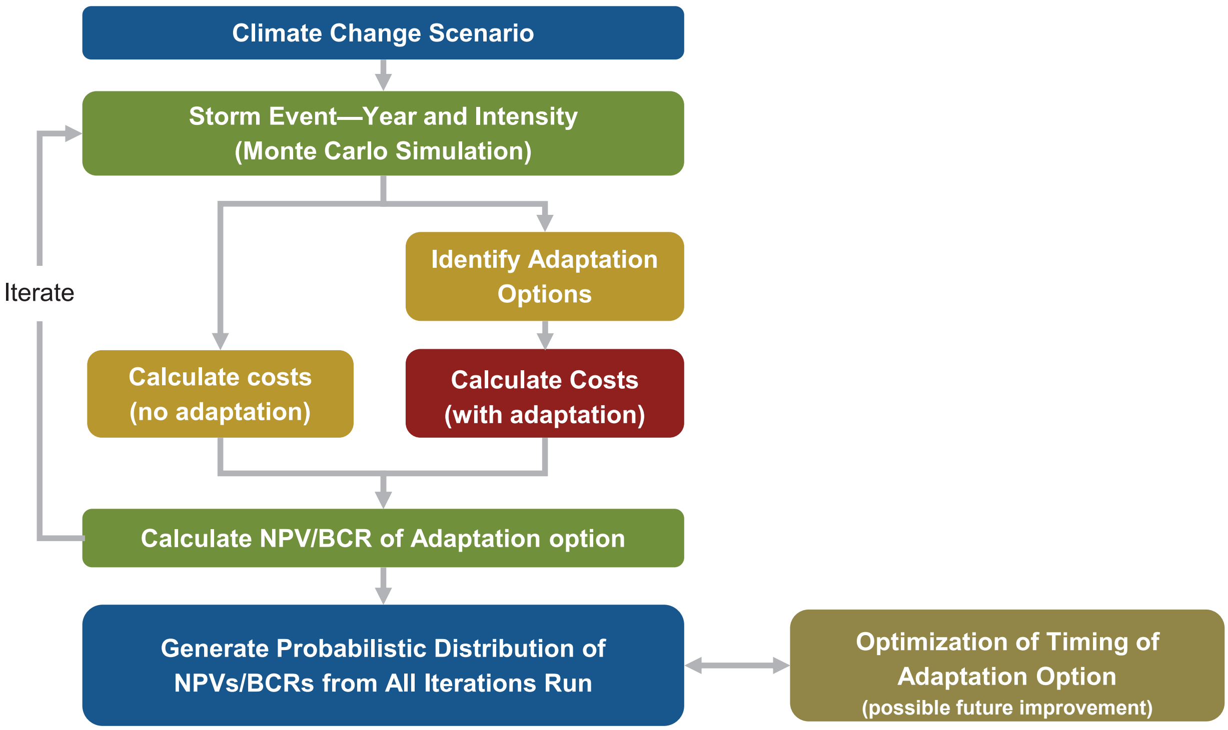
Table 11: Airport Boulevard Culvert Benefit-Cost Analysis Results: 90th Percentile, Average of All Climate Scenarios, No Property Damage Costs Included[69]

	Option One	Option Two
Scope of improvement	Six cell, 12' span x 8' rise culvert	4 cell, 21' span x 9' rise culvert
Present value of costs	\$1.7m	\$2.5m
Present value of benefits [avoided traffic congestion costs]	\$6.0m *(\$3m to \$12.7m)*	\$6.5m *(\$3.2m to \$14.4m)*
Net present value	\$4.3m *(\$1.3m to \$11.0m)*	\$4m *(\$0.7m to \$11.9m)*
Benefit-cost ratio	3.5 *(1.7 to 7.3)*	2.6 *(1.3 to 5.8)*

To address this uncertainty, a probabilistic benefit-cost analysis model has been developed which uses Monte Carlo analysis to simulate thousands of different combinations of flooding events of differing intensities under five climate / land-use scenarios over a 30-year period (a reasonable remaining design-life for the existing culvert and Option1 since it involves use of the existing culvert as well). A probability distribution is then generated from the results of all event combinations simulated. Figure 26 shows the model framework developed for the benefit-cost analysis, which is described in further detail in later sections.

[69] Costs and benefits presented in \$2013, discounted over 30 years at 7%. The ranges of possible values are shown in parentheses where pertinent.

Figure 26: Probabilistic Benefit-Cost Analysis Framework



The main model engine undertakes an analysis of each climate change scenario and each adaptation option using the following process. For each year in the 30-year appraisal period, the model:

- **Randomly generates a peak flow through the culvert:** This is done by using Monte Carlo simulation to sample from the appropriate probability function for that time period. A probability distribution for each climate change scenario has been developed using the annual return periods for each 24-hour storm event given in Table 8. The resulting function is continuous and so can not only generate 100-year, 50-year, and 25-year events according to the modeled data but intermediate values such as 23-year or 49-year events as well. Extreme events which have not yet been observed are also included: for example, if observations of storm events only go back 400 years, an estimate of a 1,000-year storm can be generated from the fitted curve as well.

  An example of a fitted distribution is shown in Figure 27. This shows the cumulative probability distribution for the input data of the "Wetter" narrative (2010-2039 time period) from Table 8 against the fitted distribution (estimated as an Extreme Value distribution[70]) generated by the @Risk software used for the Monte Carlo analysis.

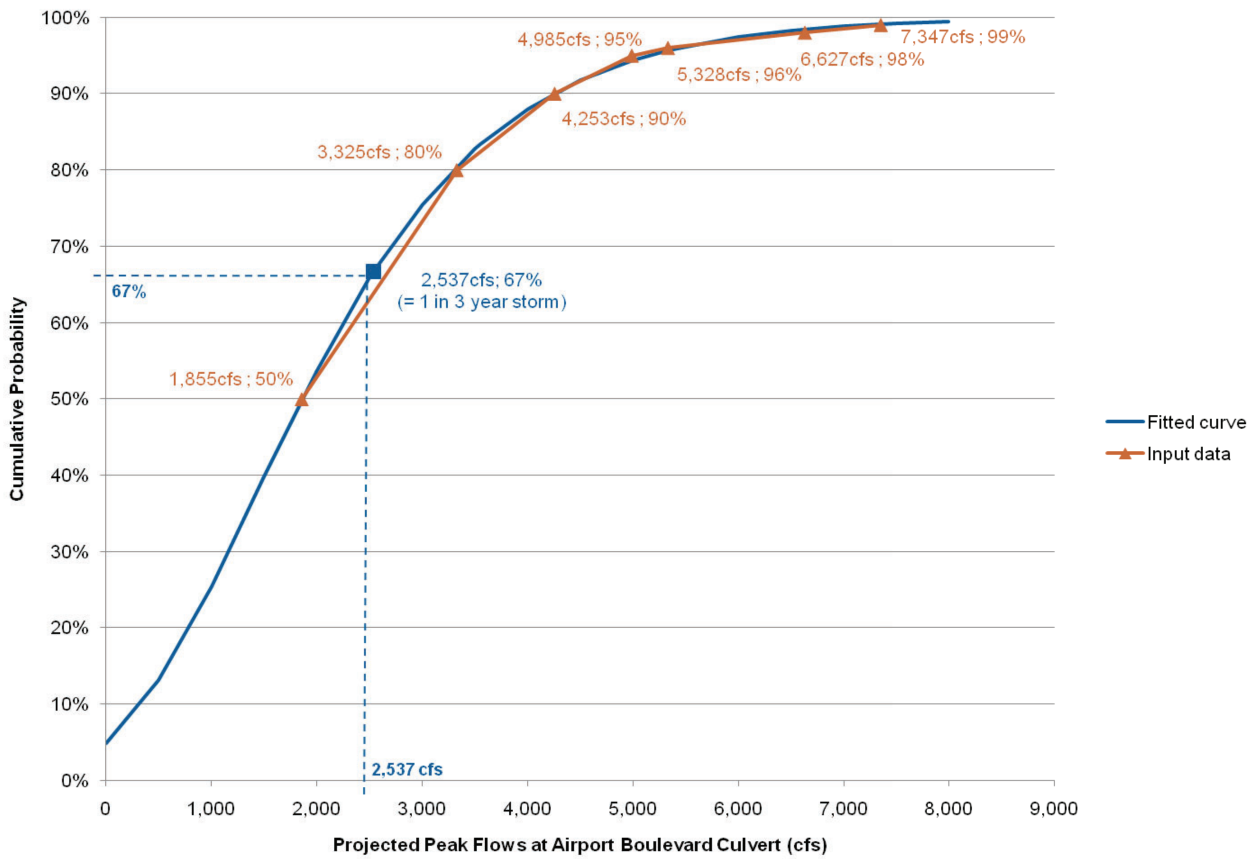
[70] In hydrology, the Extreme Value (or Gumbel) probability distribution is commonly used to describe the distribution of extreme event variables such as peak discharges. The distribution is skewed to the right to focus on maximum events, and can be used to estimate extreme events such as a 100,000-year event.

In Figure 27, the cumulative probability on the y-axis is a function of the annual return period: for a 100-year storm (peak flow 7,347 cubic feet per second [208 cubic meters per second]), in any given year, only one percent of storm events will generate a peak flow greater than this. For a five-year storm, 80% of annual storm events will generate peak flows lower than 3,325 cubic feet per second (94.2 cubic meters per second). The fitted curve also shows an example of how the peak flow through the creek can be estimated for a storm event which has not been provided in the input data: a three-year storm event (with a 66.6% probability of not being exceeded in any given year) is estimated to generate a peak flow through the creek of 2,537 cubic feet per second (71.8 cubic meters per second).

- **Determines the resultant flood elevation due to the generated flow**: This is done using the culvert stage-discharge curves provided in Figure 18, Figure 24, and Figure 25 for the existing culvert and each improvement option. Continuous functions which estimate the flood elevation for any flow rate through the culvert have been estimated using regression.
- **Determines the cost of the flood if the elevation overtops the low point of the roadway (36 feet [11 meters]):** This analysis considers the traffic disruption costs that would occur if Airport Boulevard and I-65 were closed for an assumed 24 hours[71] due to a flooding event. Using Vehicle Miles Traveled (VMT) and Vehicle Hours Traveled (VHT) outputs from the Mobile Area Transportation Study (MATS) regional travel demand model, the analysis calculates the additional vehicle hours traveled and vehicle miles traveled which would occur throughout the region if both Airport Boulevard and I-65 were closed. From this, FEMA parameters (for example, the value of travel time savings) are used to estimate the additional travel costs incurred (an avoidable economic cost). A sensitivity test has been undertaken (discussed later) whereby property damage costs are also included.
- **Calculates the flood cost savings for each of the improvement options**: Costs are relative to the flood costs of the base case (no build) with Observed precipitation depths.

[71] 24-hours is used to allow for water to recede, inspections for damage, and clean-up of the roadway.

Figure 27: Comparison of Input Data and Fitted Curve for the "Wetter" Narrative (2010-2039 Time Period)[72]



Once the impacts and costs are generated for each storm event in each year of the appraisal the model:

- Discounts the benefits (in terms of flood cost savings) for each year of appraisal back to present year values using the Office of Management and Budget rate of 7%.
- Discounts the capital costs of the improvement options (if incurred in future years)[73]
- Sums all discounted costs and savings across the entire 30-year appraisal period
- Calculates the NPV and BCR of each improvement option and records the result

The process is then repeated thousands of times, each time using a different set of randomly generated flood events. After all simulations have completed, a probability distribution showing the results of all iterations is generated.

[72] Note that the root mean square error of the fitted Extreme Value distribution versus the input data is less than 0.005 indicating a good fit. Also, whilst the fitted distribution curve does not pass through the origin, controls have been implemented in the simulation model to ensure that negative peak flows are not generated in the Monte Carlo simulation process.
[73] In this case study, the capital costs are assumed to be incurred in year zero, and therefore are not discounted. A possible improvement option would be to optimize the year of implementation of the improvement option. In this situation, the capital costs would also be discounted.

The Cost of Doing Nothing

There are likely to be substantial costs incurred if no adaptation actions are taken to address flooding at the culvert. This is because when water overtops the culvert at 36 feet (11 meters), travel will be impeded both on Airport Boulevard and I-65 (see Figure 19, Figure 20, and Figure 21). These costs can be expected to rise over time as traffic volumes increase. A sampling of the incurred costs due to traffic disruption owing to Airport Boulevard and I-65 being closed at two different time periods, 2007 and 2035, is shown in Table 12. These two time periods are the only years for which volumes are available from the MATS regional travel demand model. Disruption costs for intermediate years between 2007 and 2035 and years beyond 2035 have been calculated by using linear interpolation and extrapolation for use during the analysis.

Table 12: Traffic Disruption Costs (Per Flooding Event) With No Adaptation Actions[74]

	2007	2035
Flood elevation <36 feet	$0	$0
Flood elevation >=36 feet	$2.6m	$6.1m

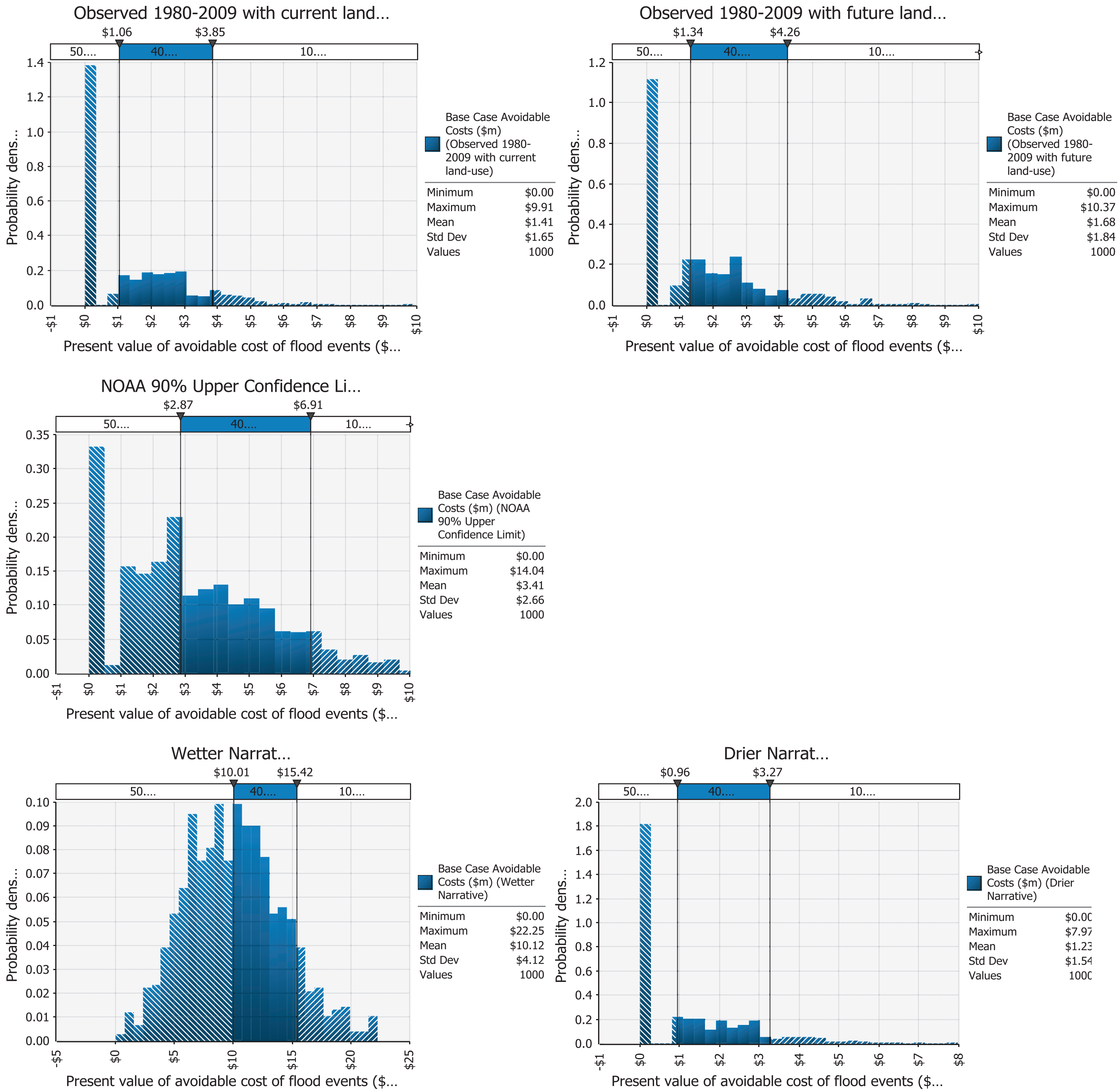
Figure 28 shows the probability distributions of cumulative traffic disruption costs[75] (discounted to present values) over 30 years for each of the climate change scenarios in the Base Case situation (no adaptation actions taken). The vertical delimiters show the 50th (median) and 90th percentile results. Thus, for the Observed conditions with current land use, over 50% of model runs had costs greater than $1.1 million and 10% had costs greater than $3.9 million. Under the “Wetter” narrative, the median disruption cost over the 30-year period was $10 million and the 90th percentile cost was $15.4 million. The maximum cost modeled was $22.3 million.

Understanding the Economic Analysis of the Adaptation Options

Economic viability of each option is assessed through its Benefit-Cost Ratio (BCR) and Net Present Value (NPV). The NPV (the discounted value of benefits, less the capital cost) gives an indication of the **magnitude** of net benefit to society. Positive NPVs indicate the project is desirable to society as a whole.

[74] Values are indexed to $2013 using the U.S. Consumer Price Index for all Urban Consumers (CPI-U)
[75] The incremental regional VMT and VHT due to shutting down Airport Blvd. and I-65 were converted into economic costs (additional travel time and mileage) using $2013 inflation adjusted (CPI-U based) FEMA unit values (FEMA, 2009). The value used for vehicle delay detour time was $41.20 per VHT and for additional vehicle mileage was $0.60 per VMT.

Figure 28: Probability Distributions of Avoidable Costs without Adaptation and Inclusion of Property Damage Costs[76]



[76] These histograms show the range of possible outcomes and their relative likelihood of occurrence. The x-axis represents the avoidable cost and the y-axis shows the probability density. In simple terms, the height of each bar gives an indication of how likely that result is to occur. The vertical delimiters show the 50th and 90th percentile results; the values at which 50% and 90% of results fall under.

The BCR (the discounted benefits divided by the capital cost) is a measure of **efficiency** or value for money, and is of principal consideration when Government is considering spending scarce funds. BCRs greater than one indicate the benefits outweigh the costs and hence a project is good value for money.

In analyzing the results of an economic analysis, the NPV and BCR should be considered together when comparing two options, particularly if the BCRs are similar in magnitude. In general, if an option has a higher BCR than its alternative, then it will also have a higher NPV. However, on occasions, an option may have a lower BCR but higher NPV than its alternative. In this situation, the incremental benefits versus the incremental costs of the two alternatives should be examined, to determine whether the additional investment of the more expensive option will deliver benefits greater than this incremental investment cost.

As this is a probabilistic analysis, where thousands of alternative flooding frequency / intensity combinations are modeled, the results also show the probability of an option's BCR being higher than one (i.e., the proportion of combinations modeled where the total value of flood damage cost avoided outweighed the investment costs). This is useful for assessing the "risk appetite" or the level of risk that Government agencies or decision-makers would be willing to take to mitigate damage costs. If an option only has a 20% chance of having a BCR over one, then this would indicate that there was a 80% chance of the asset lying idle or unused, and so on balance, the option might not be pursued by many agencies. However, some agencies may determine that even a 10% risk of damages occurring would be unacceptably high (particularly for issues affecting human safety), and so would still pursue this option. Thus, decision-makers with different risk tolerances could legitimately use the same results to justify different courses of action.

Results of the Economic Analysis of the Adaptation Options (Traffic Disruption Costs Only)

The results of the analysis for Options One and Two are shown in Table 13 and Table 14. The results show that both options are economically viable with positive NPVs and BCRs over one. On average, Option One is preferable to Option Two as it has a higher average BCR at 3.5 compared to 2.6 for Option Two. This is due to its lower capital cost and also that the additional flood protection provided (in terms of benefits) by Option Two are insufficient to outweigh its additional cost. The magnitude of the BCR and NPVs is highly dependent upon the climate scenario adopted. In this analysis, it was assumed that all five scenarios are equally likely to occur,[77] and hence the BCRs and NPVs shown in Table 11 earlier and the end column of Table 13 and Table 14 represent the mean values of all five scenarios. Table 13 and Table 14 also show the BCRs and NPVs for Options One and Two under each of the five climate and land use

[77] The Wetter and Drier narratives were developed based on climate model outputs that assumed certain IPCC greenhouse gas emission scenarios. Since the IPCC does not assign probabilities to these scenarios, probabilities cannot be assigned to the resulting climate projection information.

scenarios. Also shown is the probability that the BCR will be over one, representing the proportion of the 1,000 Monte Carlo simulations run where a BCR over one occurred.

Table 13: Airport Boulevard Culvert Adaptation Option One Economic Analysis Results under Each Climate Scenario: 90th Percentile Results, No Property Damage Costs Included[78]

Climate Scenario	1	2	3	4	5	Average (mean) of All Scenarios
Description of Scenario	Observed 1980–2009 with Current Land-use	Observed 1980–2009 with Future Land-use	NOAA 90% Upper Confidence Limit	"Wetter" Narrative	"Drier" Narrative	
Present Value of Costs	$1.7m	$1.7m	$1.7m	$1.7m	$1.7m	$1.7m
Present Value of Benefits	$3.5m	$4.0m	$6.8m	$12.7m	$3.0m	$6.0m
NPV	$1.8m	$2.2m	$5.0m	$11.0m	$1.3m	$4.3m
BCR	2.0	2.3	3.9	7.3	1.7	3.5
Probability that BCR will be over 1[79]	36%	39%	68%	97%	30%	N/A

[78] Note: Scenarios 3-5 include assumptions on future land use per the discussion in Step 5 of this case study. The costs and benefits are presented in $2013, discounted over 30 years at 7%. The present value of benefits represent the 90th percentile result from the Monte Carlo simulation (1,000 observations). These values differ slightly from the 90th percentile avoidable costs shown in Figure 28, since not all floods are avoided by the culvert upgrades; overtopping still occurs during the most extreme storm events.
[79] Based upon proportion of Monte Carlo simulations run where a BCR of 1 or above was achieved

Table 14: Airport Boulevard Adaptation Option Two Economic Analysis Results under Each Climate Scenario: 90th Percentile Results, No Property Damage Costs Included[80]

Climate scenario	1	2	3	4	5	Average (mean) of all scenarios
Description of scenario	Observed 1980-2009 with current land-use	Observed 1980-2009 with future land-use	NOAA 90% Upper Confidence Limit	"Wetter" Narrative	"Drier" Narrative	
Present Value of Costs	\$2.5m	\$2.5m	\$2.5m	\$2.5m	\$2.5m	\$2.5m
Present Value of Benefits	\$3.9m	\$4.2m	\$6.9m	\$14.4m	\$3.2m	\$6.5m
NPV	\$1.3m	\$1.7m	\$4.4m	\$11.9m	\$0.7m	\$4.0m
BCR	1.5	1.7	2.8	5.8	1.3	2.6
Probability that BCR will be over 1[81]	24%	29%	59%	97%	20%	N/A

The results show that:

- Under the "Drier" narrative and with Observed precipitation depths (using either existing or future land use), fewer extreme floods occur in the Base Case with no adaptations. Whilst the BCRs for these scenarios are above one for both Options One and Two, there is a lower probability that the benefits will outweigh the capital costs (i.e., around between 30 and 39% probability that the benefits would not be recouped).
- Under the NOAA 90% Upper Confidence Limit scenario and the "Wetter" narrative, storm events causing flooding are more frequent resulting in higher damage costs across the appraisal period. The BCRs for these scenarios are higher than those under the other scenarios with over 50% probability that the avoided damage costs would exceed the investment costs. In the "Wetter" narrative, there is around a 97% probability of achieving a BCR over one.

<u>Sensitivity Test - Inclusion of Property Damage Costs</u>

Background

The central results for this benefit-cost analysis only include the traffic disruption costs resulting from Airport Boulevard and I-65 being closed in the event of a flood. However, the flood contour boundaries presented in Figure 19, Figure 20, and Figure 21 of the main report show that many buildings east of the culvert could be affected by flooding attributable to the culvert if the water

[80] Note: Scenarios 3-5 include assumptions on future land use per the discussion in Step 5 of this case study. The costs and benefits are presented in \$2013, discounted over 30 years at 7%. The present value of benefits represent the 90th percentile result from the Monte Carlo simulation (1,000 observations). These values differ slightly from the 90th percentile avoidable costs shown in Figure 28, since not all floods are averted by the culvert upgrades; overtopping still occurs during the most extreme storm events.
[81] Based upon proportion of Monte Carlo simulations run where a BCR of 1 or above was achieved

reaches an elevation over 36 feet (11 meters). Acknowledging the aforementioned uncertainties of the location and depth of flooding east of the culvert crossing, a sensitivity analysis was undertaken to determine the effects of incorporating the estimated damage to buildings into the analysis.

Flooding of buildings incurs a number of direct and indirect economic costs, including:[82]

- **Structural Damage**: Structural damage increases as floodwaters rise.
- **Content Damage**: For example, stock held within a shop or furniture within a residential property.
- **Displacement:** Costs incurred when the occupants of a property need to move to temporary accommodation as a result of flood damage.
- **Loss of Business or Rental Income:** For example, when businesses are forced to temporarily close after a flood.
- **Value of Service:** Loss of function of a facility, such as electricity or water treatment.

Approach

This sensitivity test makes a preliminary, conservative estimate of the direct and indirect costs to properties lying within the flood contour boundaries between Montlimar Creek and I-65[83] using a methodology that broadly follows that used within the FEMA *HAZUS-MH* software used to estimate losses from flood damage.[84]

Note that there are limitations to this analysis in that:

- Only the flood boundaries are known, and not the actual flood elevation at each individual building. This would require more detailed hydrologic analysis.
- GIS data on individual land parcels (detailing building dimensions, occupancy type, and construction materials) was not available for this study, and as such, the numbers of buildings affected and building type have been estimated from publicly available imagery.
- Downstream increases to flow and attendant land use impacts associated with increasing the culvert capacity were not included. Additional detailed hydrologic analysis would be required to study this. It is highly recommended that this consideration be included on an actual project.

As a result of these limitations, these results should be treated with some caution and we recommend that further analysis using appropriate FEMA software tools be undertaken to build upon the findings here.

Using the flood contour maps provided in the main report, the number of damaged buildings and resultant economic cost for three flood elevations was estimated, as shown in Table 15. In the

[82] FEMA, 2011
[83] Flooding of properties to the east of I-65 was not considered attributable to the culvert overtopping since, without further detailed hydrologic analysis, it is even less clear if there would be sufficient volume of water to reach and inundate these structures. Also, it is possible that during a severe storm event these properties may already be flooded by the nearby Eslava Creek that lies to the east of the interchange.
[84] FEMA, 2012

analysis, we have conservatively only considered these three discrete steps rather than developing a continuous flood elevation / damage cost function. Thus, for floods below 36.3 feet (11.1 meters), no damage costs are incurred. For floods between 36.3 and 37.3 feet (11.1 and 11.4 meters), four buildings are damaged and so forth.

Table 15: Estimated Numbers of Damaged Buildings and Economic Losses Occurring from Flooding at the Airport Boulevard Culvert

Flood Elevation (feet)	Damaged Buildings[85]	Estimated Economic Cost of Damage per Flood[86]
Less than 36.3 feet	0	$0m
36.3 to 37.2 feet	4	$11.6m
37.3 to 37.5 feet	18	$106m
Greater than or equal to 37.6 feet	20	$122m

Results and Analysis

Table 16 and Table 17 show the results of the sensitivity test where property damage costs are included within the benefit-cost analysis.

Table 16: Airport Boulevard Culvert Adaptation Option One Property Damage Cost Sensitivity Test Results under Each Climate Scenario: 90th Percentile Results, Property Damage Costs Included[87]

Climate Scenario	1	2	3	4	5	Average (mean) of All Scenarios
Description of Scenario	Observed 1980–2009 with Current Land-use	Observed 1980–2009 with Future Land-use	NOAA 90% Upper Confidence Limit	"Wetter" Narrative	"Drier" Narrative	
Present Value of Costs	$1.7m	$1.7m	$1.7m	$1.7m	$1.7m	$1.7m
Present Value of Benefits	$9.7m	$11.5m	$17.8m	$83.3m	$8.2m	$26.1m
NPV	$8.0m	$9.7m	$16.1m	$81.6m	$6.4m	$24.4m
BCR	5.6	6.6	10.2	47.9	4.7	15.0
Probability that BCR will be over 1[88]	44%	50%	76%	99%	41%	N/A

[85] Estimated from aerial photos and LIDAR two-foot elevation contours.
[86] Estimated using equations and data provided within the FEMA HAZUS manual. Values indexed to $2013 using US CPI-U.
[87] Costs and benefits presented in $2013, discounted over 30 years at 7%. The present value of benefits represent the 90th percentile result from the Monte Carlo simulation (1,000 observations).
[88] Based upon proportion of Monte Carlo simulations run where a BCR of one or above was achieved.

Table 17: Airport Boulevard Culvert Adaptation Option Two Property Damage Cost Sensitivity Test Results under Each Climate Scenario: 90th Percentile Results, Property Damage Costs Included[89]

Climate Scenario	1	2	3	4	5	Average (mean) of All Scenarios
Description of Scenario	Observed 1980–2009 with Current Land-use	Observed 1980–2009 with Future Land-use	NOAA 90% Upper Confidence Limit	"Wetter" Narrative	"Drier" Narrative	
Present Value of Costs	$2.5m	$2.5m	$2.5m	$2.5m	$2.5m	$2.5m
Present Value of Benefits	$10.3m	$11.8m	$18.5m	$97.5m	$8.9m	$29.4m
NPV	$7.8m	$9.3m	$16.0m	$95.0m	$6.4m	$26.9m
BCR	4.1	4.7	7.4	38.9	3.6	11.7
Probability that BCR will be over 1[90]	38%	44%	71%	99%	35%	N/A

It can be seen that in this test, both options have BCRs over one under Observed precipitation depths and all the other scenarios indicating that they are economically viable and demonstrate very good value for money even with future uncertainty. The BCRs for Option One are higher than those for Option Two on average (15 versus 11.7) indicating that this option is preferred. However, for the "Wetter" narrative, the average NPV for Option 2 is higher than that for Option 1. Incremental analysis shows that the additional benefits (avoided costs) outweigh the incremental capital costs and so Option 2 should be considered.

To summarize, the results show that:

- Under the "Drier" narrative and Observed historical precipitation depths (with existing or future land use), even though floods are less frequent, the damage costs incurred far outweigh the capital costs for the provision of infrastructure, resulting in BCRs over one. However, the probability that the BCR would be over one is less than 50% for both Options 1 and 2.
- Under the NOAA 90% Upper Confidence Limit scenario and the "Wetter" narrative, there is a higher probability of achieving a BCR over one. Under the "Wetter" narrative, whilst the BCR for Option One is higher than that for Option Two, the NPV of the latter is greater. The incremental benefit of Option Two over Option One ($14.1 million) outweighs the $800,000 additional capital costs. Therefore, Option Two would be preferred when considering land use implications (noting the aforementioned limitations of this analysis). Under the "Wetter" narrative, almost 100% of simulations run generated BCRs over one.

[89] Costs and benefits presented in $2013, discounted over 30 years at 7%. The present value of benefits represent the 90th percentile result from the Monte Carlo simulation (1,000 observations).
[90] Based upon proportion of Monte Carlo simulations run where a BCR of one or above was achieved.

Economic Analysis Conclusions

The benefit-cost analysis shows that on average, Option One with a BCR of 3.5 would be preferred over Option Two with a BCR of 2.6, as the additional flooding protection provided by Option Two would not outweigh the additional capital cost. However, under three of the scenarios tested, the probability of achieving a BCR over one was less than 50%.

A preliminary analysis into the avoidable damage costs to properties surrounding the culvert crossing has been undertaken as a sensitivity test, which revealed that the BCRs for both Options One and Two would be greatly enhanced under all climate change scenarios, reaching 47.9 for one scenario. Considering net present values, Option Two performs equal to or better than Option One when considering land use impacts. However, it should be noted that the land use impacts are very much high-level preliminary estimates, and further analysis is recommended to determine whether floodwaters would actually reach and inundate these structures.

Step 9 –Evaluate Additional Decision-Making Considerations

While the statistical analyses provide a starting point and documented basis for making decisions, the numerical results by no means represent the final recommendation in the decision-making process. Many other factors that reflect the reality of the economy, the environment, and the social implications of the adaptation options must be considered. While the economic analysis tends to address some of these issues if all costs are considered, the tolerance for risk, the other needs of the stakeholders and the ability to fund change are equally, if not more important than the bare numbers. Any decisions made must account for all of these impacts and come from a general consensus of the engineering, planning, operations, and maintenance staff along with representatives of the affected stakeholders.

Specific considerations include items of concern for any typical project such as:

- Broader project sustainability beyond just climate change impacts (i.e., the "triple bottom line" of social, environmental, and economic concerns)
- Project feasibility and practicality
- Ongoing maintenance needs
- Maintenance funds availability
- Capital funds availability
- Stakeholders' (public and government agencies) tolerance for risk of service interruption and associated costs of all types (note: this affects how the economic analysis is perceived as well)
- Stakeholders' expected quality or level of service

After considering all of the above, decision-makers should ask the question, "Is this project worth pursuing?" Adaptation of infrastructure in response to the potential for changing climate conditions is proposed to fit within the broader context of any transportation agencies' capital improvement program and ongoing asset management efforts. Adaptation for the sake of

adaptation is not expected to meet each of the special considerations noted above and is best viewed as a component of a larger decision-making process.

Step 10 –Select a Course of Action

The economic analysis showed that the adaptation options proposed may or may not have a high chance of being cost effective; depending on how climate changes in the future. If the "Wetter" narrative were to occur, undertaking either of the adaptation options is almost certain to be cost-effective; a 97% chance or greater that the BCR would be greater than one. However, if the "Drier" narrative were to occur or if climate did not change, there is a good chance that the adaptation options proposed would not be cost-effective; a 50% chance or less that the BCR would be greater than one.

That said there is uncertainty in the probability of various rainfall events occurring even with current climate. This can have a significant bearing on the cost-effectiveness of any adaptation project as shown by the analysis of the NOAA 90% Upper Confidence Limit precipitation value. If one considered the NOAA 90% Upper Confidence Limit for current precipitation, this analysis indicated that there is *at least* a 59% chance that either of the adaptation options would be cost effective. If land use impacts are also considered, there is *at least* a 71% chance of the adaptation options being cost-effective.

This observation, along with the strong performance of the adaptation options under the "Wetter" narrative, leads to a preliminary recommended course of action to undertake adaptation Option One. Of the two adaptation options considered, this option performed best in the economic analysis considering traffic impact costs alone[91] and also had a greater probability of being cost effective under all scenarios tested. Another observation is that Option One has the best average net present value in the analysis (not considering land use flooding impacts) and a reasonable average benefit-cost ratio regardless of whether land use flooding impacts are considered. Finally, Option One is the less costly of the two options – a very relevant factor in the decision-making process.

The recommended course of action should only be seen as preliminary and subject to change pending the additional detailed analyses suggested in this document. For example, if further hydrological analysis confirms extensive flooding of surrounding properties is attributable to the culvert, more consideration should be given to adaptation Option 2. Furthermore, this study did not include a component engaging local stakeholders in a dialogue over which design would be "best" and there is no way to predict what decisions such a discussion would lead to. This discussion should acknowledge the possibility that, under any of the scenarios, there is a possibility that no serious floods will occur and the adaptation will never be "used." The

[91] Given the previously noted uncertainties in the extent of the flooding impacts on surrounding land uses caused by the culvert, more weight was given to the analysis considering just the traffic impacts.

dialogue would no doubt be heavily shaped by local risk tolerance and other factors and may very well lead to a different decision than the one arrived at through this assessment.

Step 11 – Plan and Conduct Ongoing Activities

Regardless of which design option is chosen (if any), the effects of climate on the culvert cannot be expected to remain constant as has generally been assumed in the past. Thus, the climate stressors and the culvert's performance should be monitored after the project is constructed (or it is determined that the existing culvert be left in place) and the effects on the culvert must be revisited and periodically assessed to determine if the culvert's critical design thresholds are being reached. Such monitoring and periodic assessment can help indicate if it might be necessary to implement additional improvements, change design guidelines, and / or alter operation and maintenance practices.

For a culvert, monitoring would consist primarily of keeping tabs on the most recent rainfall statistics (is rainfall becoming more frequent or intense or both?). Other questions a monitoring regime could help answer may include:

- Is land use within the drainage area becoming more impervious?
- Are storm water management facilities performing as expected?
- Is flooding becoming more frequent and widespread?
- Are there increased impacts (e.g., erosion) to the downstream channel or properties downstream from the culvert?

Conclusions

This case study has, using the *General Process for Transportation Facility Adaptation Assessments*, demonstrated how a large culvert can be analyzed for climate change impacts resulting from a projected increase in precipitation depths. Adaptation options were identified and tested using a benefit-cost framework. Ultimately, this information must be shared with local stakeholders and discussed before any locally preferred decisions can be made on what adaptive actions (if any) would be appropriate for the community.

The process shown is broadly applicable to other large culverts across the country where use of 24-hour duration precipitation projections, a standard climate model output, is appropriate. For smaller culverts where 24-hour projections may not be applicable, further research into the development of climate change IDF curves is recommended to aid in the translation of climate model outputs into inputs useful for engineering design.

4.4.2 Bridge Over Navigable Waterway Exposure to Sea Level Rise – The Cochrane-Africatown USA Bridge

Introduction

Sea level rise is a potential threat to coastal bridges of all types including non-navigable bridges, navigable moveable bridges, and navigable non-moveable bridges. With sea level rise, vertical clearances can be reduced to the point that navigation is impeded, corrosion may be enhanced, and in some cases, the bridge itself (or its approaches) may become permanently inundated. This case study assesses whether a coastal bridge, the Cochrane-Africatown USA Bridge, could limit navigation on the tidal Mobile River as a result of projected sea level rise scenarios. The sea level rise analysis for the bridge was conducted using the 11-step *General Process for Transportation Facility Adaptation Assessments* and this serves as the organizing framework for this case study.

The analysis shows that projected sea level rise may present a navigation challenge at the Cochrane-Africatown USA Bridge in one of the three sea level rise scenarios tested. However, any impediments to navigation are not anticipated to occur until late in the facility's design life. Given this finding, no immediate adaptation actions are recommended for this facility to address sea level rise although the situation should continue to be monitored over time.

Case Study Highlights

Purpose: Evaluate whether sea level rise could impede the navigational clearance of the Cochrane-Africatown USA Bridge.

Approach: The sea level rise scenarios developed previously for this study were compared to site-specific results from the USACE Sea-Level Change Curve Calculator to demonstrate an alternative approach for determining relative sea level rise for specific sites. Then, the sea level rise was evaluated against the current vertical clearance of the bridge to determine if minimum clearance requirements might be violated.

Findings: Navigational clearance of the bridge will not be affected under lesser sea level rise scenarios, but it would be affected under the 6.6 foot (200 cm) sea level rise by 2100 scenario.

Viable Adaptation Options:

- Restrict ship heights passing under that bridge, which could affect the type of ports located on either side of the bridge
- At end of bridge lifespan, replace with a higher bridge or movable bridge

Other Conclusions: Since navigational clearance may not be affected until 2100, Mobile has time to consider adaptation options. Forward-looking planning on land-use might be part of the solution. If it is too costly to replace the bridge, restricting the type of vessels that can pass under the bridge is a viable option. Doing so would change the types of facilities that could be situated upriver over time, but the Mobile community has time to adjust to such changes in land use.

Application of the General Process for Transportation Facility Adaptation Assessments

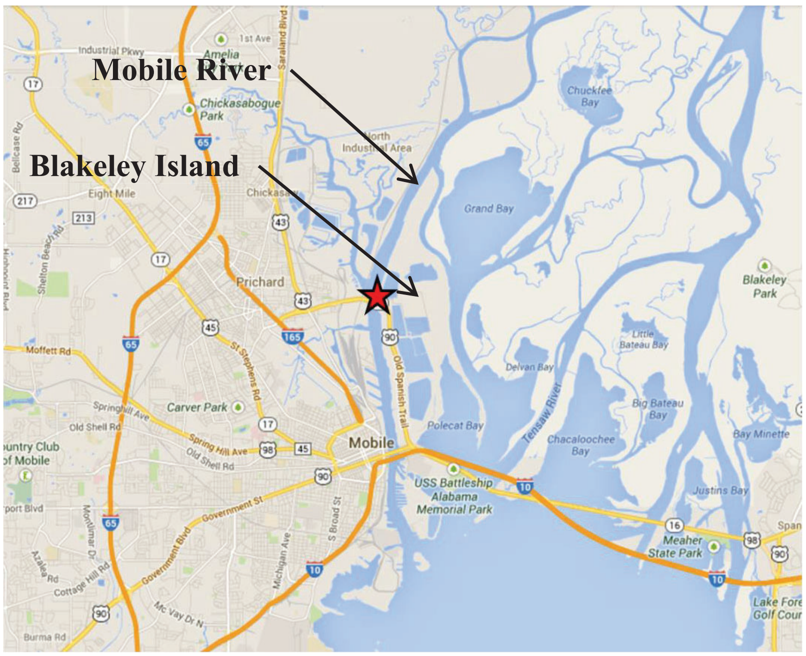
Step 1 – Describe the Site Context

The case study bridge, The Cochrane-Africatown USA Bridge, is located on the north side of the Mobile metropolitan area and carries Alternate US 90 over the tidally influenced Mobile River between Blakeley Island and the Magazine industrial area (see Figure 29). The bridge provides a link between the industrial land uses on Blakely Island and I-165. Alternate US 90 also functions as a bypass around downtown Mobile for travelers headed across Mobile Bay on I-10 (the

"Bayway") or US 90/98 (the "Causeway") to / from points north along I-165, I-65, US 43, or US 45.

The Mobile River is an important navigable waterway used both by ocean-going vessels destined for the industrial area north of the bridge and barge traffic accessing the Tennessee-Tombigbee Waterway, a canal system that connects Mobile to interior Alabama and the Tennessee River system. It should be noted that there are no other bridge crossings that would act as an impediment to navigation on the Mobile River south of the case study bridge: this is the first bridge that has the potential to limit coastal navigation for large ocean-going ships (the I-10 and US 90 crossings to the south are tunnel crossings). A future I-10 bridge over the Mobile River is currently being studied. If built, sea level rise impacts to navigation on the Mobile River should be accounted for in its design.

Figure 29: Location of the Cochrane-Africatown USA Bridge within the Mobile Metropolitan Area[92]



Surrounding land uses to the Cochrane-Africatown USA Bridge are heavily industrial (see Figure 30).

[92] Source of base map: Google Maps (as modified)

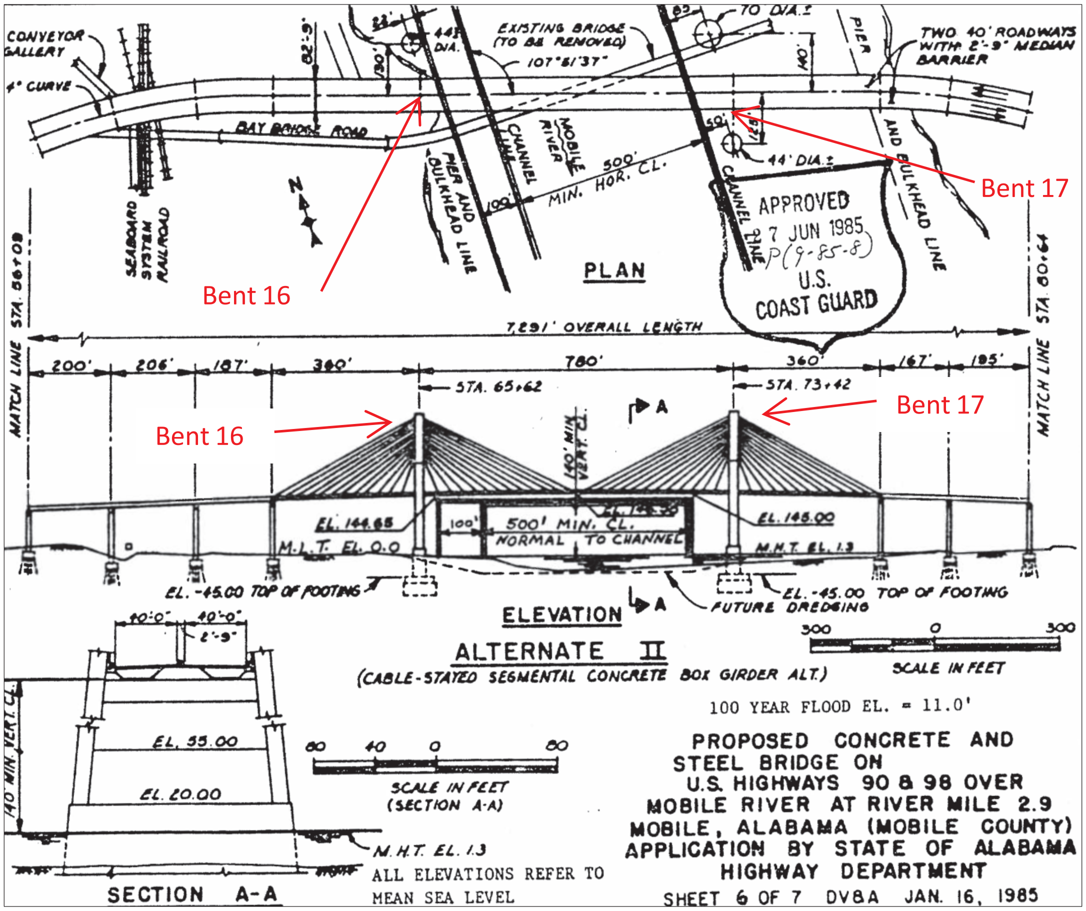
Figure 30: Land Use in the Vicinity of the Cochrane-Africatown USA Bridge[93]

Step 2 – Describe the Existing Facility

The bridge that is the subject of this case study was completed and opened in 1991. The bridge is 82.8 feet (25.2 meters) wide[94] and approximately 7,291 feet (2,222 meters) long from its western base at a location between Tin Top Lane and Paper Mill Road and its eastern base on Blakeley Island. A total of 32 bents,[95] each one assigned a unique identifying number, support the bridge from Bent 1 at the beginning of the ramp on the west end to Bent 32 on Blakeley Island. The case study analysis will focus on the portion of the bridge between Bents 16 and 17; this portion was chosen because the U.S. Coast Guard has enforced vertical clearance requirements for navigation on this portion of the bridge. Figure 31 highlights the relevant portion of the bridge in the plan (overhead) view and elevation (side) view; the same section is illustrated in a photograph in Figure 32.

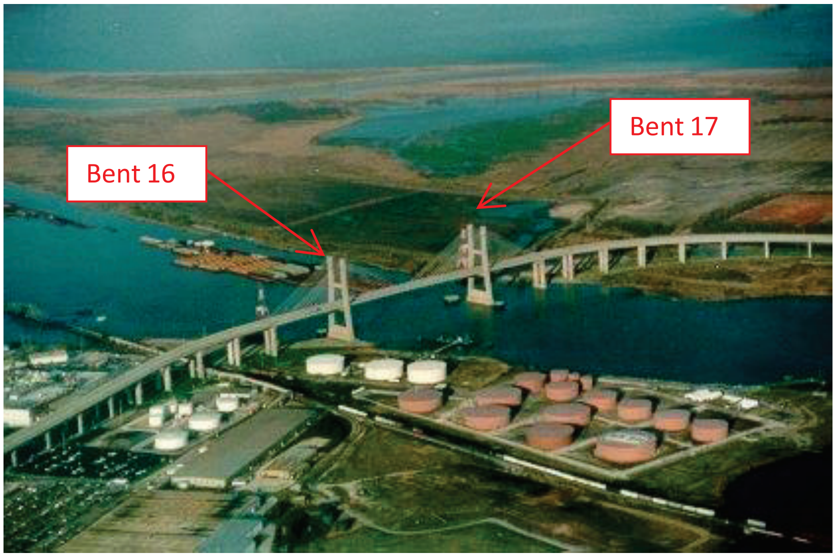
[93] Source of base map: Google Maps (as modified)
[94] Width as measured to the outside faces of the parapets. The parapets are the outside walls on either side of a bridge that are designed to prevent vehicles from careening off the structure.
[95] Bents, also known as piers, are the vertical columns supporting each bridge span along with the horizontal member, called a cap, which holds them together.

Figure 31: Plan and Elevation Views of the Cochrane-Africatown USA Bridge Showing the Section of Analysis[96]



[96] Source: USCG, 1985 (as modified). Note: All elevations shown in the image refer to mean sea level. Mean sea level is the average of the water elevations recorded at each hour of the day over the current National Tidal Datum Epoch. The tidal epoch is the specific 19-year period over which NOAA uses to obtain observations that are used to develop tidal statistics.

Figure 32: Image of the Cochrane-Africatown USA Bridge Showing the Section of Analysis between Bents 16 and 17[97]



The span between Bents 16 and 17 is 780 feet (237.7 meters) long. The superstructure[98] consists of two cable-stayed segmental concrete box girders[99] (see Figure 33). Most of the bents in the study segment consist of two square concrete piles[100] topped with a concrete pile cap.[101] Bents 16 and 17 constitute the main piers for the center span of the bridge and provide the support for two planes of high-tension steel cables. The bents extend 350 feet (106.7 meters) above mean low tide and the top of the footings for the bents are located 45 feet (13.7 meters) below mean low tide (see Figure 31). The U.S. Coast Guard bridge permit approved for the Cochrane-Africatown USA Bridge provides for a minimum 600 foot (182.9 meter) horizontal clearance between Bents 16 and 17 for passage of vessels where a minimum vertical clearance of 140 feet (42.7 meters) must be maintained between the bottom of the span and the mean high tide elevation.

Note that the elevations provided in the U.S. Coast Guard permit seen in Figure 31 are in reference to mean sea level.[102] No specific tidal epoch[103] is given in the permit. For consistency within this report, all elevations within the text are provided in reference to the North American Vertical Datum of 1988 (NAVD88) datum:[104] thus, the elevation values described in the text will not match the U.S. Coast Guard permit figures. With that in mind, the western and eastern spans have a bottom elevation of 145 and 145.3 feet (44.2 and 44.3 meters), respectively. The vertical clearance of 140 feet (42.7 meters) must be maintained between these spans and the mean high tide elevation of 1.6 feet (0.5 meters) as reported. The U.S. Coast Guard permit indicates a

[97] Source: Volkert Engineering, Planning, and Environmental Consulting, 2013 (as modified)
[98] The superstructure is the top part of the bridge and consists of the horizontal support girders, deck, and parapet walls preventing vehicles from falling off the structure.
[99] Girders are the main horizontal supporting members of the bridge.
[100] Piles are the vertical support structures extending from the bridge deck to the seabed below.
[101] The pile cap is the horizontal member that ties together the vertical piles.

provided mean high tide clearance of 143.3 feet (43.7 meters) at the western limit of the clearance envelope and 143.7 feet (43.8 meters) at the eastern limit of the clearance envelope.

Figure 33: Image of Typical Bent Configuration for Bents 1 to 15 and Bents 18 to 32 on the Cochrane-Africatown USA Bridge[105]

Step 3 – Identify Climate Stressors That May Impact Infrastructure Components

Sea level rise is the primary climate change related environmental factor considered in this study. Storm surge and high wind speeds may also be concerns for this facility. See Section 4.4.5 for a discussion of how a bridge can be analyzed for storm surge impacts coupled with sea level rise.

Step 4 – Decide on Climate Scenarios and Determine the Magnitude of Changes

The impacts of three potential global sea level rise values, based on projected climate changes, were considered for this case study. The values considered include:

- One foot (0.3 meters) of global sea level rise by 2050
- 2.5 feet (0.8 meters) of global sea level rise by 2100
- 6.6 feet (two meters) of global sea level rise by 2100

The one and 2.5 foot (0.3 and 0.8 meter) values represent two points in time in an intermediate sea level rise scenario that was selected in the *Climate Variability and Change in Mobile, Alabama* report[106] as the midrange of National Research Council estimates. The high projection of 6.6 feet (two meters) is derived from recent research indicating that the rates of sea level rise might actually be faster than initially thought based on a growing understanding of ice sheet melting dynamics; its use here illustrates an application of the precautionary principle whereby,

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[102] Mean sea level is the average of the water elevations recorded at each hour of the day over the current National Tidal Datum Epoch. The tidal epoch is the specific 19-year period over which NOAA uses to obtain observations that are used to develop tidal statistics.
[103] The tidal epoch is the specific 19-year period over which NOAA uses to obtain observations that are used to develop tidal statistics.
[104] A datum is a reference plane used as a starting point from which to measure elevations.
[105] Source: Google Earth Street View
[106] USDOT, 2012

even though there is scientific uncertainty, plausible possibilities should be considered in order to prevent harm to the public. For more information on how these scenarios were developed, please refer to the *Climate Variability and Change in Mobile, Alabama* report.[107]

In addition to global sea level rise values, local vertical land movements may have a significant exacerbating or mitigating effect on local sea level change at any given transportation facility. Considering vertical land movements allows one to determine local relative sea level rise, the factor most relevant to facility design. Vertical land movement at the Cochrane-Africatown USA Bridge is 0.03 inches per year (0.7 millimeters per year) of uplift as obtained from U.S. Geologic Survey (USGS) data.[108] Thus, land movements at the site have a slight mitigating effect on global sea level rise. Relative sea level rise at the Cochrane-Africatown USA Bridge is therefore 0.9 feet (0.27 meters) for the intermediate scenario in 2050, 2.3 feet (0.7 meters) for the intermediate scenario in 2100, and 6.4 feet (1.95 meters) for the high scenario in 2100.

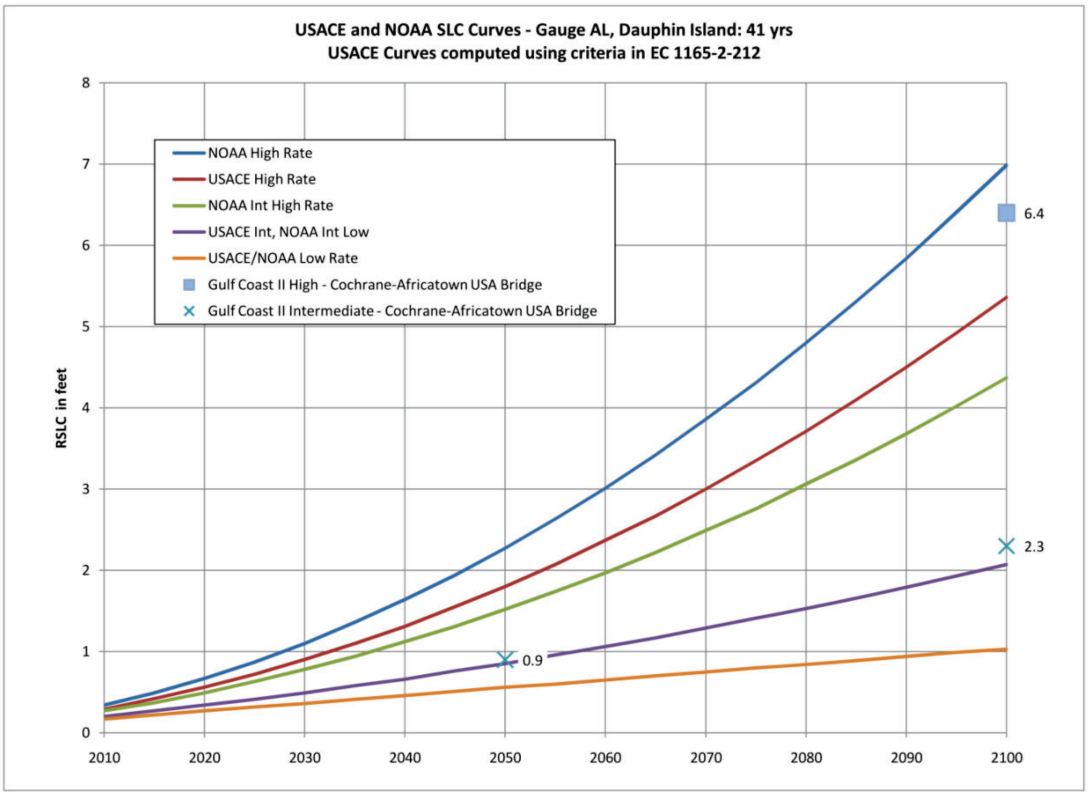
For locations outside the Mobile region, sea level rise scenarios can be generated using guidance developed by the U.S. Army Corps of Engineers (USACE).[109] The latest version of this guidance was released with an associated on-line calculation tool called the *Sea-Level Change Curve Calculator* that links to key tidal stations where a sufficient period of record exists to support projections of sea level rise with consideration of vertical land movement. To illustrate its use, sea level projections from the tool were obtained and compared with the aforementioned projections developed for the Gulf Coast Study Phase 2. The calculations are based on the Dauphin Island tide gauge and assume a starting date of 2010. The only information required to be provided to the *Sea-Level Change Curve Calculator* is selection of the closest NOAA gauge which is provided as an option from several gauges around the country. Once this is selected the land subsidence rate of 0.05 inches per year (1.22 mm/yr) at Dauphin Island is automatically provided. The user then selects the end date, 2100, for the project and the option to include the NOAA curves. The computations were based on the USACE Guidance.[110]

The results are presented in Figure 34 and include curves from (1) the USACE showing low, medium, and high estimates and (2) from NOAA showing low, low intermediate, high intermediate, and high estimates. The NOAA curves shown in Figure 34 are calculated based on criteria contained in a NOAA report[111] presenting global sea level rise scenarios. These global sea level rise scenarios were developed for use in the National Climate Assessment[112] draft report which indicates a one to four foot (0.3 to 1.2 meter) likely range for global sea level rise and a larger 0.7 to 6.6 foot (0.2 to two meter) range suggested for use in risk-based analyses (an approach consistent with that used in this report). Both the USACE and NOAA curves are based

[107] USDOT, 2012
[108] USDOT, 2012
[109] USACE, 2013
[110] USACE, 2011
[111] Parris, Bromirski, Burkett, Cayan, Culver, and Hall, 2012
[112] NOAA, 2013c

on the original parabolic equations presented in the National Research Council (NRC) report[113] on the engineering implications of responding to sea level rise. The equation includes a linear term that is used to simulate the current sea level trend and the nonlinear parabolic term which accounts for acceleration of the current sea level trend due to climate change projections. The differences between the USACE and NOAA curves stem from different sources and / or publication dates regarding global sea level rise projections which are key input parameters for the calculation. For further detail see the USACE guidance,[114] NOAA report,[115] and book by NRC.[116]

Figure 34: Comparison of Relative Sea Level Rise Projections for Dauphin Island, Alabama[117]



As shown in Figure 34, the sea level rise projections generated for this study at the Cochrane-Africatown USA Bridge lie within the envelope of the USACE and NOAA curves at Dauphin Island. In addition, the 2050 one foot (0.3 meter) and 2100 2.5 foot (0.8 meter) projections for sea level rise agree with the trend of the USACE intermediate and NOAA intermediate low projections. The highest sea level rise projection identified for this study, 6.6 feet (two meters), lies slightly below the high projection for NOAA and about 1.2 feet (0.4 meters) above the high

[113] NRC, 1987
[114] USACE, 2013
[115] Parris et al., 2012
[116] NRC, 1987
[117] USACE, 2013

projection from the USACE. Thus, the sea level rise projections for this study are consistent with both the USACE and NOAA guidance one might use to do adaptation studies in other coastal locations around the country. The three sea level rise values used in this study do not match exactly with the projections shown in Figure 34 because the most conservative and most extreme scenarios were not the ones selected for use in the Gulf Coast Study. Analysis of sea level rise impacts on the navigational clearance of bridge spans in other areas may choose to analyze the higher and lower bounds of sea level rise projections.

Step 5 – Assess Performance of the Existing Facility

The progression of sea level rise over the ensuing decades could present challenges for maintaining the required navigation allowances for the Cochrane-Africatown USA Bridge. Table 18 shows the projected clearances at the western and eastern side of the navigation envelope. Given the required minimum vertical clearance of 140 feet (42.7 meters), global sea level rise in combination with vertical land movement does not violate the navigation requirements for the main span clearance limits in the year 2050 when there is a 1 foot (0.3 meter) rise or in the year 2100 when there is a 2.5 foot (0.8 meter) rise. This is because the initial design provided an allowance above the 140 foot (42.7 meter) minimum requirement. However, global sea level rise will violate the permit requirement under the 6.6 foot (two meter) global sea level rise scenario for 2100. In this scenario, the vertical clearance near Bent 16 is only 137 feet (41.8 meters) and near Bent 17 is 137.3 feet (41.8 meters), well below the 140 foot (42.7 meter) minimum mandated in the U.S. Coast Guard permit.

Step 6 – Identify Adaptation Option(s)

No adaptations are required for the 2050 one foot (0.3 meter) and the 2100 2.5 foot (0.8 meter) global sea level rise scenarios. For the projected year 2100 6.6 foot (two meter) global sea level rise scenario, several adaptive design options to accommodate sea level rise for the Cochrane-Africatown USA Bridge were considered and are listed in Table 19 along with the pros and cons for each.

It should be noted that any potential sea level rise issues on the Cochrane-Africatown USA Bridge will occur after the conclusion of its design life, which, assuming the typical 75 year lifespan for a bridge, ends in 2066 (although it is common for bridges in well-maintained condition to remain in service well past their designated design lives). Given this, it might very well be the case that a full replacement of the existing structure with a design that accounts for anticipated sea level changes will be a more cost-effective solution than retrofitting the existing structure.

For bridges with navigable spans that might cause significant navigational impacts due to sea level rise during their design lives, future bridge rehabilitation efforts will need to consider significant modifications to reduce navigation clearance related impacts such as elevating the

deck. Investigation of how substructures can be extended, modified, or completely rebuilt will need to be studied at the time of rehabilitation on a case-by-case basis.

Table 18: Clearances for Navigation at the Cochrane-Africatown USA Bridge under Projected Sea Level Rise Values

Global Sea Level Rise	Relative Sea Level Rise[118]	Clearance Between Bottom Slabs / Beams and Mean High Tide[119]	
		West Side of Envelope	East Side of Envelope
Current Conditions	None	143.4 feet (43.7 meters)	143.7 feet (43.8 meters)
2050 - One Foot (0.3 meters)	0.9 feet (0.3 meters)	142.5 feet (43.4 meters)	142.8 feet (43.5 meters)
2100 - 2.5 Feet (0.75 meters)	2.3 feet (0.7 meters)	141.1 feet (43.0 meters)	141.4 feet (43.1 meters)
2100 - 6.6 Feet (2.0 meters)	6.4 feet (2.0 meters)	137.0 feet* (41.8 meters)	137.3 feet* (41.8 meters)

*Does not meet minimum vertical clearance requirement of 140 feet (42.7 meters)

Step 7 – Assess Performance of the Adaptation Option(s)

The performance of each of the adaptation options discussed across the three sea level rise values evaluated are discussed below:

- **Option 1** maintains the existing bridge and therefore the 140 foot (42.7 meter) clearance requirement would not be met under the 2100 6.6 foot (two meter) scenario. Under this adaptation option, it would be accepted that vessel passage would be restricted to smaller vessels. This option would meet the requirements under the other sea level rise values tested.
- **Option 2** would meet the U.S. Coast Guard permit requirements under the year 2100 6.6 foot (two meter) global sea level rise scenario and all the other sea level rise values tested.
- **Option 3** would eliminate the bridge completely by replacing it with a tunnel, therefore the clearance requirements would be met under all sea level rise values investigated. However, this option is likely to be less desirable as it would eliminate the main route from hazardous materials to and from the port facility which was likely one of the primary purposes for construction of the Cochrane Africatown-USA Bridge.
- **Option 4** would meet the U.S. Coast Guard permit requirements under the year 2100 6.6 foot (two meter) global sea level rise scenario and all the other sea level rise values tested but, due to the vulnerability of moveable bridges to power loss and damage from storms, this option is not likely to be chosen.

[118] These values account for global sea level rise along with an estimated land movement uplift of 0.1 feet (three centimeters) in 2050 and 0.2 feet (6.1 centimeters) in 2100.
[119] As reported in the Coast Guard permit diagram seen in Figure 31.

Table 19: Adaptation Options Considered for the Cochrane-Africatown USA Bridge

Possible Alternatives	Description	Pros	Cons
Restrict Marine Traffic (Option 1)	• The existing bridge would remain as is and marine traffic would be limited to only those vessels whose specific clearance requirements would be maintained	• No capital costs associated with a large project undertaking • No traffic outages	• Restrictions placed on larger vessel classes
Raise the Superstructure (Option 2)	• Rebuild the upper portion of the towers to accommodate the higher profile while preserving the stay cable angles so that the edge girders could be reused • Raise approach roadways to meet the raised center span. • Potentially reuse existing approach spans, main span foundations and towers below the roadway.	• Can elevate roadway to meet 6.6 feet (two meter) sea level rise.	• Large project undertaking with few comparable examples • Traffic outages during construction • Large capital and maintenance costs • Lengthy project development time
Replace the Bridge with a Tunnel (Option 3)	• Eliminate the existing bridge and replace with tunnel crossing	• Eliminates need for navigational clearances under all sea level rise scenarios	• Large capital and maintenance cost • Eliminates the only roadway for hazardous materials across the Mobile River as restrictions are in place for the I-10 and US 90 tunnels. • Long period of traffic disruption
Retrofit or Replacement of Fixed Span with Moveable Bridge Center Span (Option 4)	• Replace or retrofit center span of bridge with a moveable span	• Involves work only within center span • Allows larger vessels passage under bridge	• Vulnerabilities to loss of power or damage to mechanical systems • Interruption to highway traffic • FHWA policy is to provide fixed bridges wherever practicable

Step 8 – Conduct an Economic Analysis

An economic analysis was not included in this case study but is recommended for facility-level adaptation assessments. See Section 4.4.1 for an example of how an economic analysis was applied to a culvert exposed to changes in precipitation due to climate change.

Step 9 – Evaluate Additional Decision-Making Considerations

Other important factors that will likely influence whether the Cochrane-Africatown USA Bridge is adapted to accommodate sea level rise include:

- How existing or proposed port facilities utilizing the Mobile River to the north of the Cochrane-Africatown USA Bridge decide to adapt to sea level rise. If these facilities are compromised by sea level rise (or even if they are not), one broader-focused adaptation option might be to consider locating or relocating these facilities south of the bridge thereby reducing the navigation height requirements for the structure such that it only needs to accommodate barge traffic.
- How vehicle traffic volumes on the bridge evolve over time through shifts in population, land uses, or loss of service on other major roadways. Increased traffic volumes greater than the current service level design might provide added impetus to making changes to the bridge whereby sea level rise adaptations could be worked in. On the other hand, if sea level rise negatively affects adjoining land use to the point where they are abandoned, the need for the bridge within the larger transportation network may be diminished. In some cases, not likely in this one, a bridge may no longer be necessary if the land uses it serves are no longer viable due to an increase in sea levels.
- Potential local concerns from adjacent neighborhoods in response to plans for a higher bridge.

Step 10 – Select a Course of Action

In the case of this bridge, given the scenarios identified, no adaptive actions are recommended at this time. As sea level rise is a relatively gradual phenomenon (even considering its projected acceleration after mid-century) time will allow for continual evaluation of changes in actual sea levels as they relate to the curves shown in Figure 34. As 2100 approaches, it might be that the actual trend line is closer to the 2.5 foot (0.8 meter) scenario rather than the 6.6 foot (two meter) scenario and no adaptations will be required. In the case of the Cochrane-Africatown USA Bridge, it makes little sense to re-design the facility for the 6.6 foot (two meter) scenario until more information supports or conflicts this trend line. If the projections bear out as shown in Figure 34, this might become apparent by mid-century and a decision should be made then on how to proceed.

Step 11 – Plan and Conduct Ongoing Activities

Since whether sea level rise will follow the upper trend line that requires adaptation is highly uncertain at this time and sea level rise is gradual, the key recommendation for this analysis is to monitor trends in actual sea levels over time in the Mobile region and compare them to the

projected sea level rise scenarios in Figure 34. This ongoing evaluation will inform conversations about the likely trends and may lead to identification of inflection points where trend analysis may indicate that the threat is more or less severe than projected. Local officials may wish to identify a "trigger threshold" for actual sea level change (informed by the sea level rise curves and the projected time required to plan, design, finance, and construct a chosen adaptation option). The trigger level would be less than the level of change required to violate the U.S. Coast Guard 140 foot (42.7 meter) requirement such that, when the trigger threshold is crossed, planning and financing activities for adapting the facility need to commence.

Conclusions

This case study has, using the *General Process for Transportation Facility Adaptation Assessments*, demonstrated how a bridge can be analyzed for sea level rise impacts on navigation. Navigation requirements for the Cochrane-Africatown USA Bridge were violated under only one of the climate scenarios tested; the scenario projecting 6.6 feet (two meters) of sea level rise by 2100. Several adaptation concepts were discussed for this scenario. Ultimately, this information must be shared with local stakeholders and discussed before any locally preferred decisions can be made on what adaptive actions would be appropriate for the community and when would be the best time to implement them.

The process shown is broadly applicable to bridges across the country where sea level rise has an influence. Bridges over navigable channels would need to be investigated for clearance reductions due to sea level rise and determine if any remedial action would need to be implemented. Ultimately, this effort is best handled at a planning level in a coordinated manner amongst all bridges along a shipping channel: it makes little sense to adapt one bridge to accommodate sea level rise if other bridges along the channel are not adapted as well and may impede access. It is recommended that such analyses be undertaken for navigable waterways across the country that are subject to sea level rise and have bridges that may impede maritime commerce.

4.4.3 Bridge Approach Embankment Exposure to Sea Level Rise – US 90/98 Tensaw-Spanish River Bridge (Western Approach)

Introduction

Sea level rise, irrespective of storm surge, is a potential threat not only to low-lying coastal roadways at risk of permanent inundation but also to more elevated roadways on embankments in the coastal zone where increased wave heights and energies impacting embankments can cause scouring and erosion. Continual inspection and maintenance is required to prevent the scouring and erosion that can result in significant loss of embankment material, loss of pavement sections, or ultimately, the complete breach of a roadway embankment.

This case study assesses whether a tidally influenced approach roadway leading to the west abutment of the US 90/98 Tensaw-Spanish River Bridge can withstand changes in wave energy impacts as a result of various projected sea level rise scenarios. Specifically, the effect of increased wave heights from sea level rise on required embankment protection and roadway overtopping are studied. This case study does not analyze increased wave heights in combination with storm surge impacts. A complete analysis for embankment vulnerability would require analysis of both wave impacts and storm surge impacts. In addition, this study only analyzes a portion of the approach road to the embankment. Potential flooding as a result of sea level rise with or without storm surges should also be analyzed to determine if roadway inundation does occur and to what extent.

Case Study Highlights

Purpose: Evaluate whether a tidally-influenced bridge approach embankment can withstand the increased heights of waves due to sea level rise. Overtopping of roadway and erosion impacts were considered.

Approach: The height at which waves would impact the embankment was calculated to determine how high the riprap slope protection would need to be, and then evaluated against the estimated size of the current riprap slope protection.

Findings: If adequately maintained, the current riprap slope protection would likely provide adequate protection from wave impacts under the 30 cm and 75 cm by 2050 sea level rise scenarios, although temporary inundation of the approach road could occur. Under the 200 cm by 2100 scenario, the existing riprap protection is not adequate to protect against wave impacts, and permanent overtopping of the roadway could occur.

Viable Adaptation Options:

- Ensure existing riprap protection is well maintained
- Extend the current riprap slope protection
- Raise the elevation of the riprap slope protection, approach, and bridge

Other Conclusions: Problems associated with sea level rise would likely occur late in the design life of the approach. Therefore, it may be cost-effective to wait until a replacement is due before making major structural changes.

The assessment, limited as it was, determined that one of the three sea level rise scenarios tested would lead to permanent inundation of the approach roadway and would require adaptation actions such as raising the embankment elevation and enhancing the rip-rap protection measures (the existing roadway elevation and rip-rap measures were adequate for the other two sea level rise scenarios). However, as sea level rise is a gradual phenomenon and two of the three

scenarios do not result in permanent inundation, it is recommended that no immediate action be taken towards this end and that the situation be monitored.

Although this case study focuses on an embankment approach to a bridge abutment with open water on both sides, the general analytical methods demonstrated here can also be applied to other coastal embankments, including causeways, coastal roadway embankments parallel to shorelines, or barrier island roads that are (or may become) subject to regular wave impacts due to increases in sea levels. Wave impact analysis at bridge embankments is a particularly complicated process, and it is recommended that it be performed by a qualified coastal engineer. The serviceable life of the facility should also be considered when analyzing impacts of sea level rise forecasts in the future. Comparing the expected remaining life of a bridge to the projected sea level elevation can help planners develop their approach to adaptation as discussed in Step 6, "Identify Adaptation Option(s)", below.

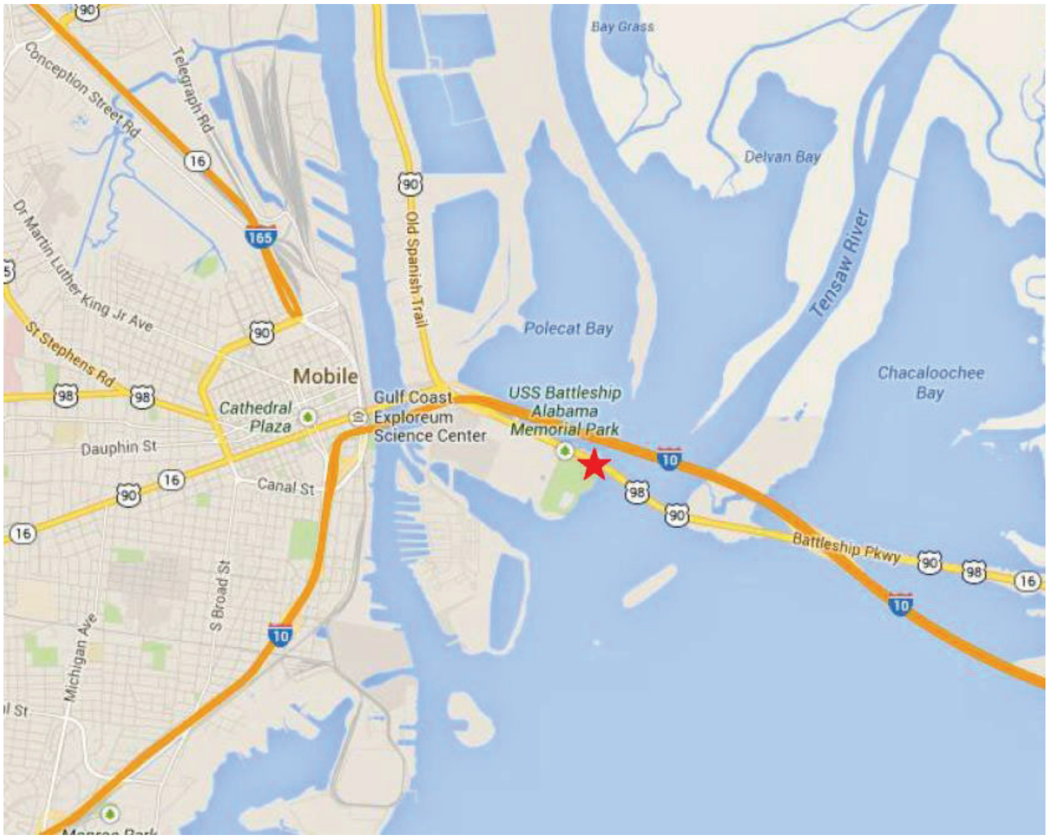
The sea level rise and wave analysis for the embankment was conducted using the 11 step *General Process for Transportation Facility Adaptation Assessments* and this serves as the organizing framework for this case study.

Application of the General Process for Transportation Facility Adaptation Assessments

Step 1 – Describe the Site Context

The case study approach roadway is located on Blakeley Island, just east of downtown Mobile, and acts as the western landing point for a bridge carrying US routes 90 and 98 (Battleship Parkway) over the mouth of the Tensaw and Spanish Rivers (see Figure 35). The bridge represents the beginning of the Battleship Parkway Causeway (the "Causeway"), a combination of causeways and bridges allowing US 90/98 to traverse the nearly eight mile (12.5 kilometer) wide tidally influenced Mobile Bay. The Causeway was the first route across the Bay and was followed later by the bridge carrying the Jubilee Parkway (I-10), commonly referred to as the "Bayway." Today, the Causeway provides an important alternate route across Mobile Bay in the event of an incident that limits the use of I-10. It is also a key link serving the USS Alabama Battleship Memorial Park and commercial businesses on the islands along the Causeway. The subject approach roadway is located on the northern end of the Battleship Memorial Park, about one mile (1.6 kilometers) east of the interchange between US 90/98 and I-10 (Exit 27).

Figure 35: Location of the US 90/98 Tensaw-Spanish River Bridge within the Mobile Metropolitan Area[120]



Step 2 – Describe the Existing Facility

The US 90/98 Tensaw-Spanish River Bridge has separate eastbound and westbound spans: the westbound (northern) span was built in 1963 and the eastbound (southern) span was built in 1995. The bridge is 42.8 feet (13 meters) wide[121] and approximately 1,426 feet (435 meters) long from the western abutment on Blakeley Island to the eastern abutment. A total of 12 bents,[122] each one assigned a unique identifying number, support the bridge. The bents are numbered sequentially from Bent 1 at the west abutment to Bent 12 at the east abutment.

An aerial and topographic view of the western approach roadway and abutment can be seen in Figure 36 and an oblique aerial photo in Figure 37. A plan (overhead) view from ALDOT can be seen in Figure 38, while profile (side) views are shown in Figure 39 and Figure 40.

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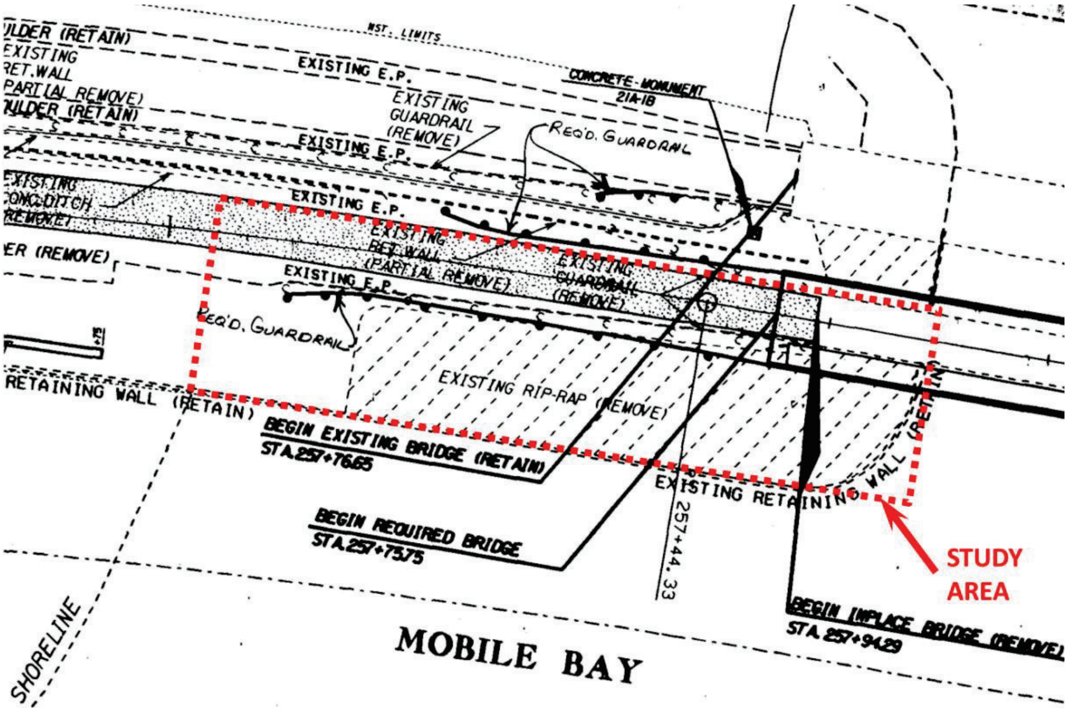
[120] Source of base map: Google Maps (as modified)
[121] Width as measured to the outside faces of the parapets. The parapets are the outside walls on either side of a bridge that are designed to prevent vehicles from careening off the structure.
[122] Bents, also known as piers, are the vertical columns supporting each bridge span along with the horizontal member, called a cap, which holds them together.

Figure 36: Aerial Image and Topography of the West Abutment of the US 90/98 Tensaw-Spanish River Bridge[123]

Figure 37: Oblique Aerial Image of the South Side of the US 90/98 Tensaw-Spanish River Bridge West Abutment[124]

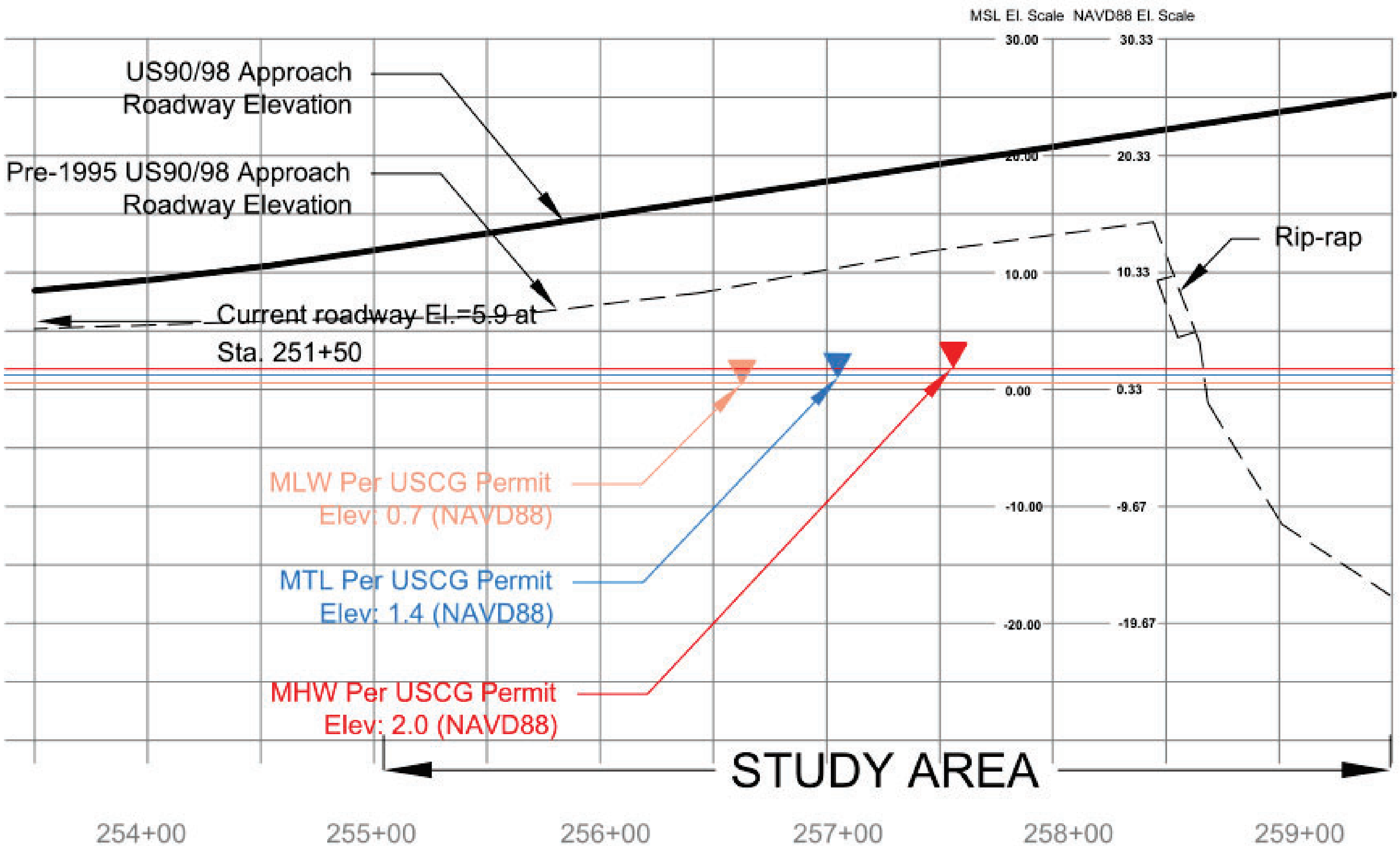
[123] Source of base map data: City of Mobile GIS. Note: All elevations shown are in relation to the North American Vertical Datum of 1988 (NAVD88).
[124] Source of image: Google Maps

Figure 38: Plan of the West Abutment of the
US 90/98 Tensaw-Spanish River Bridge Showing the Area of Analysis[125]



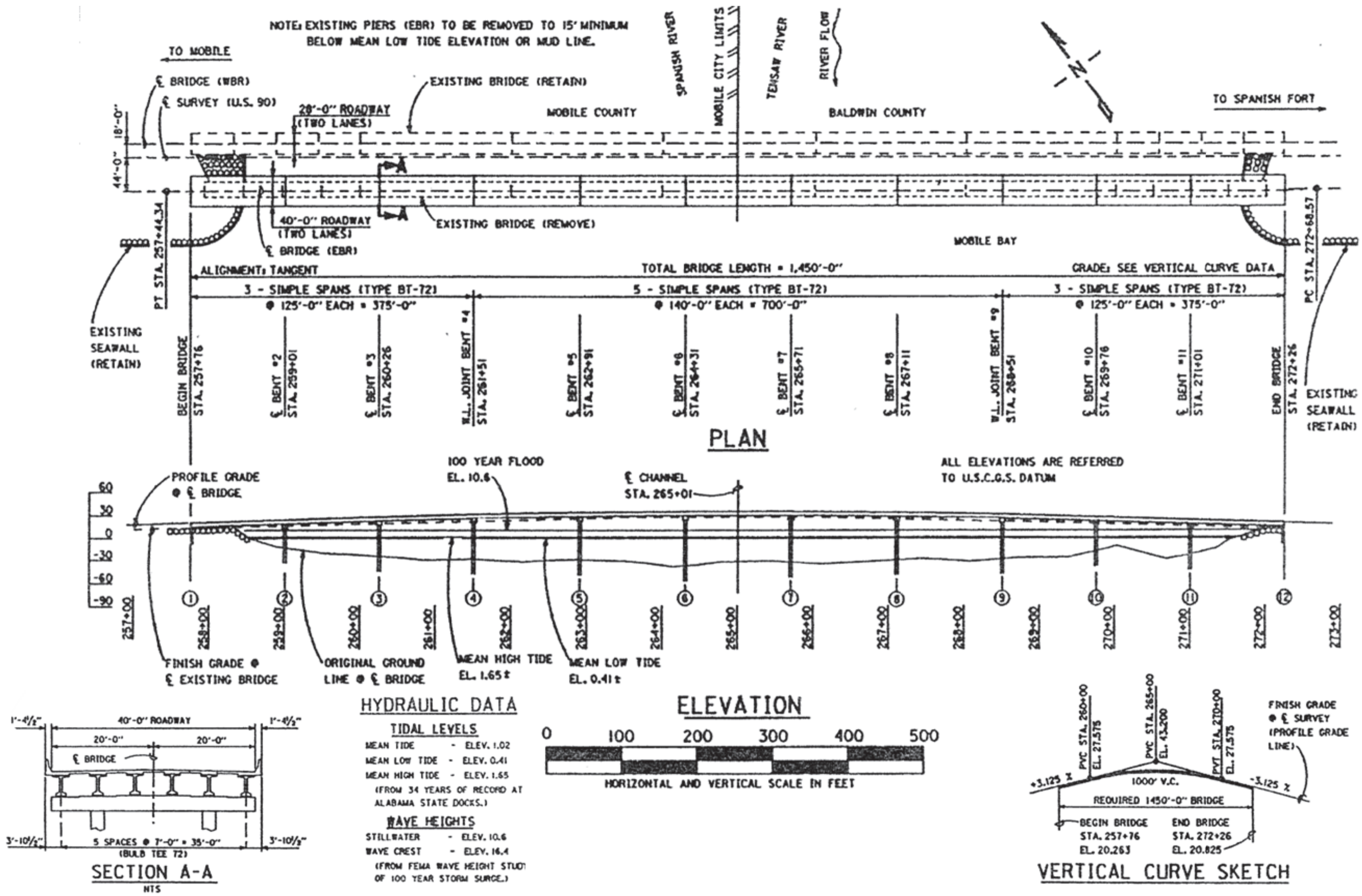
[125] Source: ALDOT, 1994 (as modified). Note: Figure obtained from the original 1995 construction drawings. All elevations shown refer to mean sea level. Mean sea level is the average of the water elevations recorded at each hour of the day over the current National Tidal Datum Epoch. The tidal epoch is the specific 19-year period over which NOAA uses to obtain observations that are used to develop tidal statistics.

Figure 39: Profile of the Western Approach Roadway to the US 90/98 Tensaw-Spanish River Bridge[126]



[126] Source: ALDOT, 1994 (as modified). Note: Figure obtained from the original 1995 construction drawings. All elevations shown refer to mean sea level. Mean sea level is the average of the water elevations recorded at each hour of the day over the current National Tidal Datum Epoch. The tidal epoch is the specific 19-year period over which NOAA uses to obtain observations that are used to develop tidal statistics.

Figure 40: Plan and Elevation of US 90/98 Tensaw-Spanish River Bridge[127]



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127 USCG, 1995. Note: All elevations shown refer to mean sea level. Mean sea level is the average of the water elevations recorded at each hour of the day over the current National Tidal Datum Epoch. The tidal epoch is the specific 19-year period over which NOAA uses to obtain observations that are used to develop tidal statistics.

The case study analysis will focus on wave impacts on the western approach roadway to the bridge, specifically the south side of the embankment as this is the location susceptible to wind-generated wave impacts. The west embankment of the Tensaw-Spanish River Bridge extends approximately 300 feet (91 meters) westward from the water's edge under the span. This studied segment of the bridge approach is highlighted in the plan view of the structure shown in Figure 38 and the elevation shown in Figure 39.

The approach roadway in the study area begins at an elevation of 5.9 feet[128] (1.8 meters), approximately 725 feet (221 meters) west of the abutment. The roadway increases in elevation as it reaches the bridge. The western end of the eastbound span is at an elevation of 20.9 feet (6.4 meters) and rises at a grade of 3.1% towards the center of the span (see Figure 39). The south side of the west abutment slopes down to a bulkhead with the top at an approximate elevation of 5.5 feet (1.7 meters). The maximum slope of the southern embankment was found to be 4 horizontal to 1 vertical. The south side of the west approach roadway and abutment currently is reinforced with riprap[129] revetment[130] with a D_{50}[131] of approximately 15 inches (38.1 centimeters) in size and a thickness of 3 feet (0.9 meters). The elevation of the seabed of Mobile Bay directly in front of the abutment is -0.7 feet (-0.2 meters).

Step 3 – Identify Climate Stressors That May Impact Infrastructure Components

Changes in wave impacts due to sea level rise are the primary climate change related environmental factors considered in this study. However, sea level rise and its saturation effect on soil stability above the current sea level elevation should be a consideration in the design of future facilities and the inspection of existing facilities. Storm surge based erosion and scour at the bridge abutment is another key environmental factor that should be considered in the design and protection of the approach roadway. Section 4.4.4 of this report provides a detailed study of this climate stressor for the same case study bridge abutment.

Step 4 – Decide on Climate Scenarios and Determine the Magnitude of Changes

Three sea level rise values were considered for this case study based on projected climate changes and land movements in Mobile: one foot (0.3 meters), 2.5 feet (0.8 meters), and 6.6 feet (two meters). The one foot (0.3 meter) scenario is projected to occur around 2050 while the other two scenarios capture the range of possible future changes by 2100 (uncertainty on sea levels increases further into the future). For more information on how these scenarios were developed, please refer to the *Climate Variability and Change in Mobile, Alabama* report.[132] See Step 4 in

[128] All elevations in the text of this document are in NAVD88.
[129] Riprap consists of loose stone placed in a manner to provide erosion protection or armoring over a soil area.
[130] Revetments are, "a layer or facing of rock, dumped or hand-placed to prevent erosion, scour, or sloughing of a structure or embankment" (FHWA, 1989).
[131] Dx denotes rock gradation percentages for which the distribution of individual stones will have diameters of X percentage of the sample batch smaller than the stated measurement value. For example, for D_{50} = 10 inches (254 millimeters), 50% of the rocks in the batch will have diameters smaller than 10 inches (254 millimeters) and 50% will have diameters greater than 10 inches (254 millimeters).
[132] USDOT, 2012

Section 4.4.2 for a discussion of how sea level rise scenarios can be generated for locations outside of the Mobile region.

The revetment riprap size and location required to protect an approach roadway against wave impacts are determined by the wave heights. These may be a combination of local wind-generated waves and ocean waves based on the amount of wave energy and associated wave height remaining after the wave transformation processes between the coast and the site's location within the bay. The largest waves that can impact the embankment may be limited by the available water depth directly in front of the embankment. This wave height, known as the depth-limited wave height, will likely increase as sea levels rise, resulting in deeper water that is capable of sustaining larger waves. During long term sea level rise, sedimentation could preclude the development of significantly deeper water depths at a given location, but for this analysis it is assumed that water depth increases with sea level rise.

As water depth increases there may also be a point at which the depth no longer limits wave height at the structure. This could be the case at a particular structure if the design wave height is less than the depth-limited wave height condition. Wave heights are primarily dependent on water depth, wind speed, and fetch.[133] In the open ocean or under surge conditions, water depth may increase to a point where the wind speed and fetch under a given design scenario are the limiting factors instead of the depth-limited wave conditions. In these conditions, design wave heights should either be calculated using guidance from the *Coastal Engineering Manual*[134] or determined through detailed modeling. For this analysis, it is assumed depth-limited wave height conditions prevail for the various sea level rise scenarios considered.

For this study, a comparison of the riprap slope protection required to protect against depth-limited waves was made for current conditions along with the three sea level rise values previously discussed. Depth-limited, wind-generated waves without storm surge influences were chosen for this analysis to provide a clear view on how sea level rise can affect the magnitude of wave impacts without coupling them with other factors such as storm surges. A depth-limited wave was chosen because they are the largest waves that can occur at a location for a given depth of water. For this study, two types of depth-limited wave heights were calculated: (1) breaking wave heights detailing the highest point a wave reaches prior to breaking and (2) the significant wave height[135] of incident waves at the toe of a structure. The impact of sea level rise on the depth-limited wave heights in front of the west approach roadway of the Tensaw-Spanish River Bridge can be found in Table 20.

[133] FHWA, 2004. Fetch refers to the area over water where the wind is unobstructed with fairly uniform speed and direction.
[134] USACE, 2012
[135] Significant wave height is the average height of the one-third largest waves for a specific set of wind, fetch and water depth conditions.

Table 20: Sea Level Rise Impacts on Depth-Limited Wave Heights along the Western Approach Roadway to the US 90/98 Tensaw-Spanish River Bridge

Sea Level Rise	MHW Elevation[136] Feet (Meters)	Water Depth in Front of Embankment Feet (Meters)	Depth-Limited Breaking Wave Height[137] Feet (Meters)	Depth-Limited Significant Wave Height[138] Feet (Meters)
None	2.0 (0.6)	2.7 (0.8)	2.1 (0.6)	1.6 (0.5)
One foot (0.3 Meter)	3.0 (0.9)	3.7 (1.1)	2.8 (0.9)	2.2 (0.7)
2.5 Foot (0.8 Meter)	4.5 (1.4)	5.2 (1.6)	4.0 (1.2)	3.1 (0.9)
6.6 Foot (2.0 Meter)	8.6 (2.6)	9.3 (2.8)	7.2 (2.2)	5.6 (1.7)

Step 5 – Assess Performance of the Existing Facility

The progression of sea level rise over the next several decades and its impact on sustaining taller waves could present challenges for maintaining the functionality of the roadway embankment. To design for riprap slope protection, the size of the stone used for protection was determined. Then, the height at which the crashing waves impact the embankment was calculated to determine how high the slope protection needs to be.

Riprap Slope Protection Sizing

For the purpose of this study, the size of the riprap slope protection required to armor against taller waves was analyzed. In addition, the height of wave run-up along the embankment was analyzed under each scenario. Specifically, for each of the three sea level rise values along with current conditions, the medium mass of rock (M_{50})[139] required to withstand wave impacts was determined using the Hudson equation[140] from the U.S. Army Corps of Engineers (USACE) *Coastal Engineering Manual*.[141] The Hudson equation is as follows:

$$M_{50} = \frac{\rho_S H^3}{K_D \left(\frac{\rho_S}{\rho_W} - 1\right)^3 cot\alpha}$$

[136] Mean High Water (MHW) is the average of all high tide elevations during the day over the current National Tidal Datum Epoch. The tidal epoch is the specific 19-year period over which NOAA uses to obtain observations that are used to develop tidal statistics. The MHW elevation was taken from the ALDOT bridge plans (ALDOT, 1994) and adjusted to the NAVD88 vertical datum.
[137] Breaking wave heights are calculated as 78% of the water depth directly in front of the study area (USACE, 2002).
[138] Significant wave heights are calculated as 60% of the water depth at the toe of the structure (USACE, 2002).
[139] The medium mass of rock refers to the average riprap stone size required to provide armoring for slope stability.
[140] Hudson, 1974
[141] USACE, 2002

Where,

H Characteristic wave height[142]
M_{50} Medium mass of rocks
ρ_S Mass density of rocks[143]
ρ_W Mass density of water[144]
α Slope angle[145]
K_D Stability coefficient (a value of two for this case study) [146]

Once the mass of rock was determined, the equivalent cube length of rock, which is the minimum size of rock required to provide armor slope stability, was calculated. The equivalent cube length of rock was determined using the following equation:[147]

$$D_{n50} = \left(\frac{M_{50}}{\rho_S}\right)^{1/3}$$

Where,

D_{n50} Equivalent cube length of median rock
M_{50} Medium mass of rocks
ρ_S Mass density of rocks[148]

Table 21 provides the standard riprap class sizes from ALDOT's *Standards and Specifications for Highway Construction*. Class sizes from this table are chosen based upon the medium mass and equivalent cube length of rock calculated. Table 22 provides a summary of the required mass, equivalent cube length, and selected riprap class for wave impacts for depth-limited breaking waves under current conditions and the three sea level rise scenarios at the embankment.

Under current conditions, the riprap size required to provide slope protection is Class 1, the smallest size provided in Table 21. The current riprap slope protection at the site is estimated to be Class 3. Under the three sea level rise scenarios, as the depth-limited breaking wave height increases, the class of riprap slope protection needed increases as well. See Table 21.

[142] The characteristic wave height is the depth-limited breaking wave height for the purposes of this study.
[143] Assumed to be 165 pounds per cubic foot (2,643 kilograms per cubic meter) for this case study
[144] 64 pounds per cubic foot (one tonne per cubic meter)
[145] 14° based on a 4/1 horizontal to vertical slope
[146] Based on rough, angular stone for breaking waves where characteristic wave height is equal to $H_{1/10}$ wave height (USACE, 1984)
[147] Hudson, 1974
[148] Assumed to be 165 pounds per cubic foot (2.6 tonnes per cubic meter) for this case study.

Table 21: ALDOT Standard Riprap Classes[149]

Riprap Class	Weight Range – D_{10} to D_{90} Pounds (kilograms)	D_{50} Size	
		Pounds (kilograms)	Inches (millimeters)
1	10 – 100 (4.5-45.4)	50 (22.7)	10 (254)
2	10 – 200 (4.5-90.7)	80 (36.3)	12 (305)
3	25 – 500 (11.3-227)	200 (90.7)	15 (381)
4	50 – 1,000 (22.7-454)	500 (227)	22 (559)
5	200 – 2,000 (227-907)	1,000 (454)	28 (711)

Table 22: Revetment Riprap Size Calculation Results to Withstand Wave Impacts at the Western Approach Roadway to the US 90/98 Tensaw-Spanish River Bridge

Projected Sea Level Rise	Depth-Limited Breaking Wave Height, H Feet (Meters)	Medium Mass of Rocks, M_{50} Pounds (Kilograms)	Equivalent Cube Length of Rocks, D_{50} Inches (Millimeters)	Riprap Class
None	2.1 (0.6)	46 (21.0)	8 (203)	1
One foot (0.3 Meter), Yr. 2050	2.8 (0.9)	121 (54.9)	11 (279)	2
2.5 Foot (0.8 Meter), Yr. 2100	4.0 (1.2)	340 (154.3)	15 (381)	3
6.6 Foot (2.0 Meter), Yr. 2100	7.2 (2.2)	1,971 (894.0)	27 (686)	5

Wave Run-Up Calculations for Slope Protection

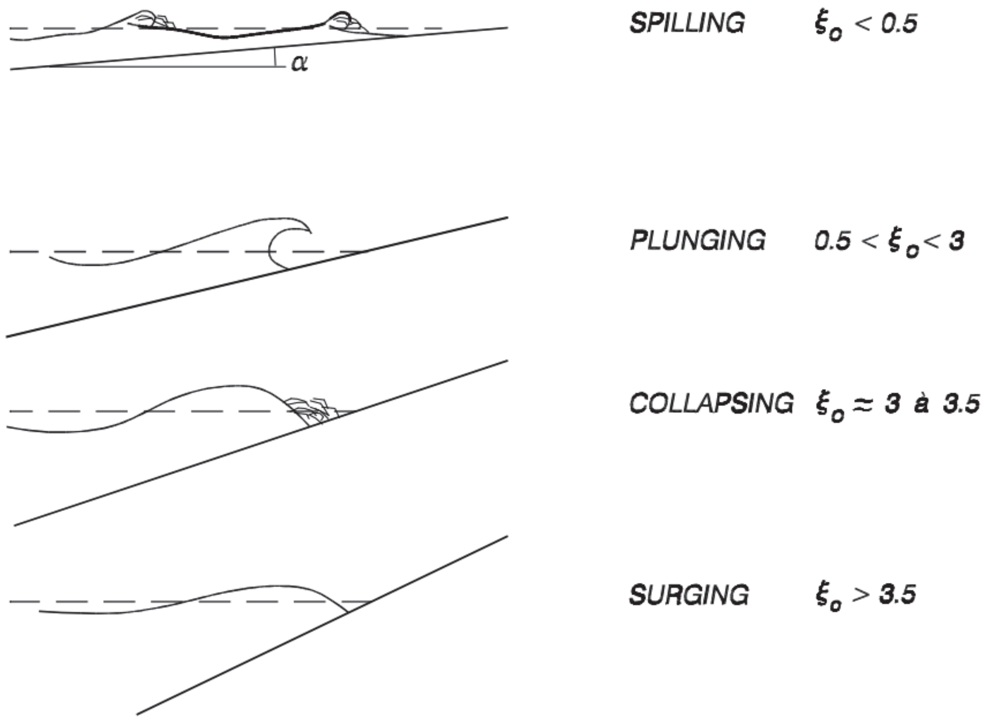
The next portion of the case study involves determining the height at which protection is needed to withstand wave impacts. Wind-generated waves and their associated peak wave periods[150] cause waves to break on sloping structures. The heights of the embankment that are susceptible to the crests and troughs of breaking waves are known as run-up (R_u) and run-down (R_d) heights, respectively. For the purposes of this case study, run-down and wave impacts to the toe

[149] ALDOT, 2012
[150] Peak wave periods refer to the time period between the most energetic waves in the total wave spectrum at a specific point.

of the embankment were not factored in because of the presence of an existing bulkhead. In cases where a bulkhead is not present, run-down and toe impacts would need to be calculated to determine the length down the embankment slope that protection would be needed.

Run-up and run-down are dependent on surf-similarity pattern or the Iribarren number[151] (ξ) which identifies the type of breaking wave. Breaking wave types identified through calculation of the Iribarren number are illustrated in Figure 41.

Figure 41: Types of Breaking Waves on an Impermeable Slope[152]



For the purposes of this study, irregular wave types were selected to represent a natural sea state with variability as opposed to a "monochromatic" (i.e., regular) wave pattern. As the Iribarren number increases, wave run-up height also increases. For example, "surging" waves, with an Iribarren number greater than 3.5, would generate higher run-up values at a particular embankment than the other wave types shown in Figure 41.

For irregular waves, the Iribarren number is calculated as shown in the following equation:[153]

$$\xi_{om} = \frac{\tan\alpha}{\sqrt{s_{om}}}$$

[151]Battjes, 1974
[152] USACE, 2002 (Table VI-5-1)
[153] USACE, 2002

Where,
ξ_{om} Iribarren number for mean wave period
α Slope angle[154]
s_{om} Mean wave steepness for mean wave period

To calculate the Iribarren number, the mean wave steepness was first calculated. The mean wave steepness is the ratio between the depth-limited significant wave height and the mean wave length and can be determined through the following formulae:

$$s_{om} = {}^{H_S}/_{L_{om}} = {}^{2\pi}/_{g} \times {}^{H_S}/_{T_m^2}$$

Where,
s_{om} Mean wave steepness
H_S Depth-limited significant wave height
L_{om} Mean wave length
g Acceleration due to gravity[155]
T_m Mean wave period ($= 0.87 \times T_p$)
Where,
T_p Wave period corresponding to the peak of the wave spectrum[156]

Calculation of the peak wave periods is described in detail in Part II-2-2 of the *Coastal Engineering* Manual.[157] The goal of this study is to evaluate the wave impact with various SLR scenarios. The wind-induced wave condition is considered the controlling scenario for design of the revetment as it produces a more erosive state than typical waves which would not be expected to be the controlling conditions for this specific case. For this study, the peak wave period was obtained from the Steady State Spectral Wave (STWAVE) model results for storm surge related wave conditions, since standalone modeling of extreme wind event wave conditions was not modeled for non-surge storm conditions as part of this study. The storm surge scenario used to obtain the peak wave period was the Hurricane Katrina Base Case Scenario as detailed in Section 4.4.4 . The storm surge peak wave period was selected for this study since waves at this location were depth-limited during the surge, which parallels the assumptions of depth limited wave for the non-surge extreme wind conditions. If wave modeling data is not available, the peak wave period would need to be calculated in accordance with the *Coastal Engineering Manual.*[158]

[154] 14° based on 4/1 horizontal to vertical slope
[155] 32.2 feet per second squared (9.8 meters per second squared)
[156] This period is the time between peak waves of the wave spectrum (derived from the STeady State spectral WAVE model [STWAVE] employed on this project).
[157] USACE, 2002
[158] USACE, 2002

Once the Iribarren number is calculated, determining the wave run-up height is the next step of the process. The wave run-up value at the two percent probability of exceedance level ($R_{u2\%}$) on an impermeable rock slope[159] was calculated using the following equation:[160]

$$\frac{R_{u2\%}}{H_S} = \begin{Bmatrix} A \times \xi_{om} & for\ 1.0 < \xi_{om} \leq 1.5 \\ B(\xi_{om})^C & for\quad \xi_{om} > 1.5 \end{Bmatrix}$$

Where,

$R_{u2\%}$ Wave run-up value at the two percent probability of exceedance level
H_S Depth-limited significant wave height
ξ_{om} Iribarren number for mean wave period
$A_{2\%} = 0.96$
$B_{2\%} = 1.17$
$C_{2\%} = 0.46$

The $A_{2\%}$, $B_{2\%}$, and $C_{2\%}$ values are coefficients that vary based upon the permeability of the embankment slope. For various slope types, the coefficients can be determined using Figure VI-5-11 and Table VI-5-5 in the *Coastal Engineering Manual*.[161]

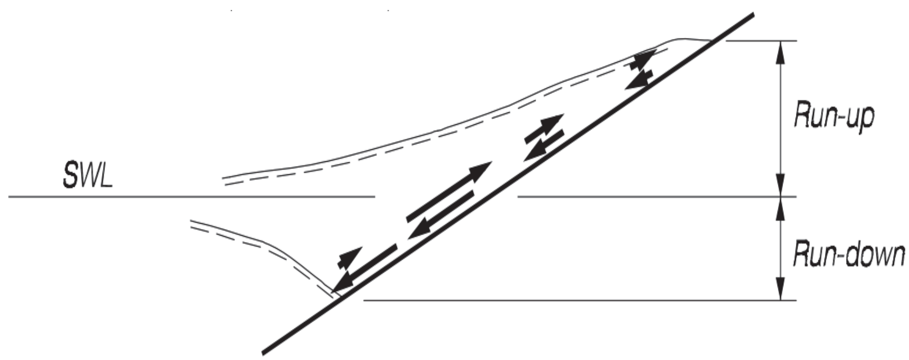
The 2% wave run-up value represents the run-up height with a probability of occurrence being twice for every 100 waves. Presently, this is the most common run-up parameter used to determine the height of riprap slope protection. Table 23 provides the results of the run-up height and elevation calculations for determination of the vertical extent of wave impacts and revetment riprap protection placement. Figure 42 provides a representation of the difference between Surface Water Levels (SWL) and the run-up crest elevation. For the purposes of this study, SWL is assumed to be the Mean High Water (MHW)[162] level in each of the scenarios.

[159] Impermeable slopes represent embankments with impermeable (asphalt, concrete, etc.) surfaces and fine core materials that limit porosity. Permeable slopes would represent rubble-mound structures (USACE, 2002).
[160] USACE, 2002 (Equation VI-5-12). Also see Delft Hydraulics, 1989.
[161] USACE, 2002
[162] Mean High Water (MHW) is the average of all high tide elevations during the day over the current National Tidal Datum Epoch. The tidal epoch is the specific 19-year period over which NOAA uses to obtain observations that are used to develop tidal statistics.

Table 23: Revetment Riprap Run-up Elevation Calculation Results at the US 90/98 Tensaw-Spanish River Bridge Western Approach Roadway Embankment

Sea Level Rise	MHW Elevation Feet (Meters)	Run-up Height ($R_{U2\%}$) Feet (Meters)	Run-up ($R_{U2\%}$) Crest Elevation[163] Feet (Meters)
None	2.0 (0.6)	3.1 (0.9)	5.1 (1.6)
One foot (0.3 Meter)	3.0 (0.9)	3.9 (1.2)	6.9 (2.1)
2.5 Foot (0.8 Meter)	4.5 (1.4)	5.1 (1.6)	9.6 (2.9)
6.6 Foot (2.0 Meter)	8.6 (2.6)	8.1 (2.5)	16.7 (5.1)

Figure 42: Diagram of Surface Water Level versus Run-up[164]



Currently, with no sea level rise, wave run-up is halted only 0.4 feet (0.1 meters) above the bulkhead and does not reach the approach roadway elevation of 5.9 feet (1.8 meters) located approximately 725 feet (221 meters) west of the span. Under the projected 2050 one foot (0.3 meter) sea level rise scenario, the wave run-up reaches an elevation of 6.9 feet (2.1 meters), which does not overtop the embankment but will most likely lead to temporary inundation of the approach road. As waves subside, the temporary inundation will in turn subside. Under the projected 2100 2.5 feet (0.8 meter) sea level rise scenario, the wave run-up reaches an elevation of 9.6 feet (2.9 meters). Again, under this scenario, temporary inundation of the approach roadway will occur but will subside. Under the highest sea level rise 2100 projected scenario of 6.6 feet (two meters), wave run-up comes within 2.5 feet (0.8 meters) vertically of the beginning of the bridge span. In this scenario, overtopping does occur along the approach roadway beginning at a location 80 feet (24.4 meters) west of the embankment. In this scenario, the MHW

[163] Elevation where 2% of wave run-up heights reach.
[164] Note: For the purposes of this study, Surface Water Level (SWL) in the diagram represents MHW (USACE, 2002).

elevation will create a permanent inundation of the approach roadway. Figure 43 and Figure 44 illustrate the MHW level and calculated run-up heights and their impact upon the embankment and approach roadway in plan and profile views, respectively.

As previously noted, the current riprap protection in place on the project is estimated to be Class 3 riprap (D_{50} = 18 inches [45.7 centimeters]) with a thickness of 3 feet (0.9 meters) and has been place on the embankment slope from the bulkhead to elevation 10.3 feet (3.1 meters). Table 24 provides a summary of the required size of the riprap slope protection and height of wave run-up at the case study embankment. The existing riprap slope protection meet the design standards under the 2050 one foot (0.3 meter) and the 2100 2.5 feet (0.75 meter) projected sea level rise scenarios. In the 2100 6.6 feet (3.0 meters) sea level rise scenario, the existing riprap slope protection is neither large enough or at a high enough elevation to protect against wave impacts.

Figure 43: Plan of the US 90/98 Tensaw-Spanish River Bridge Approach Roadway and Western Embankment with MHW and 2% Run-up Water Levels

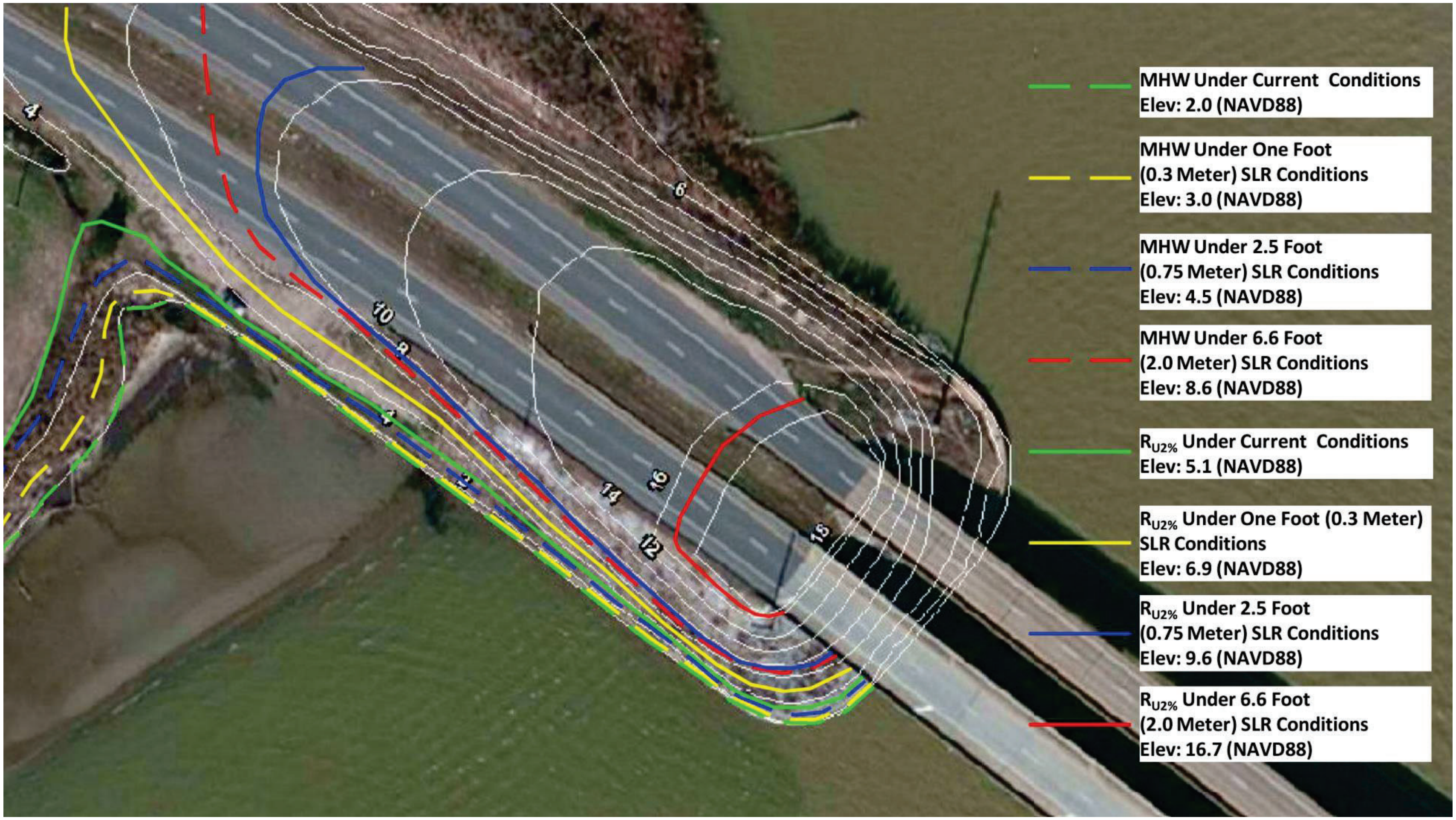
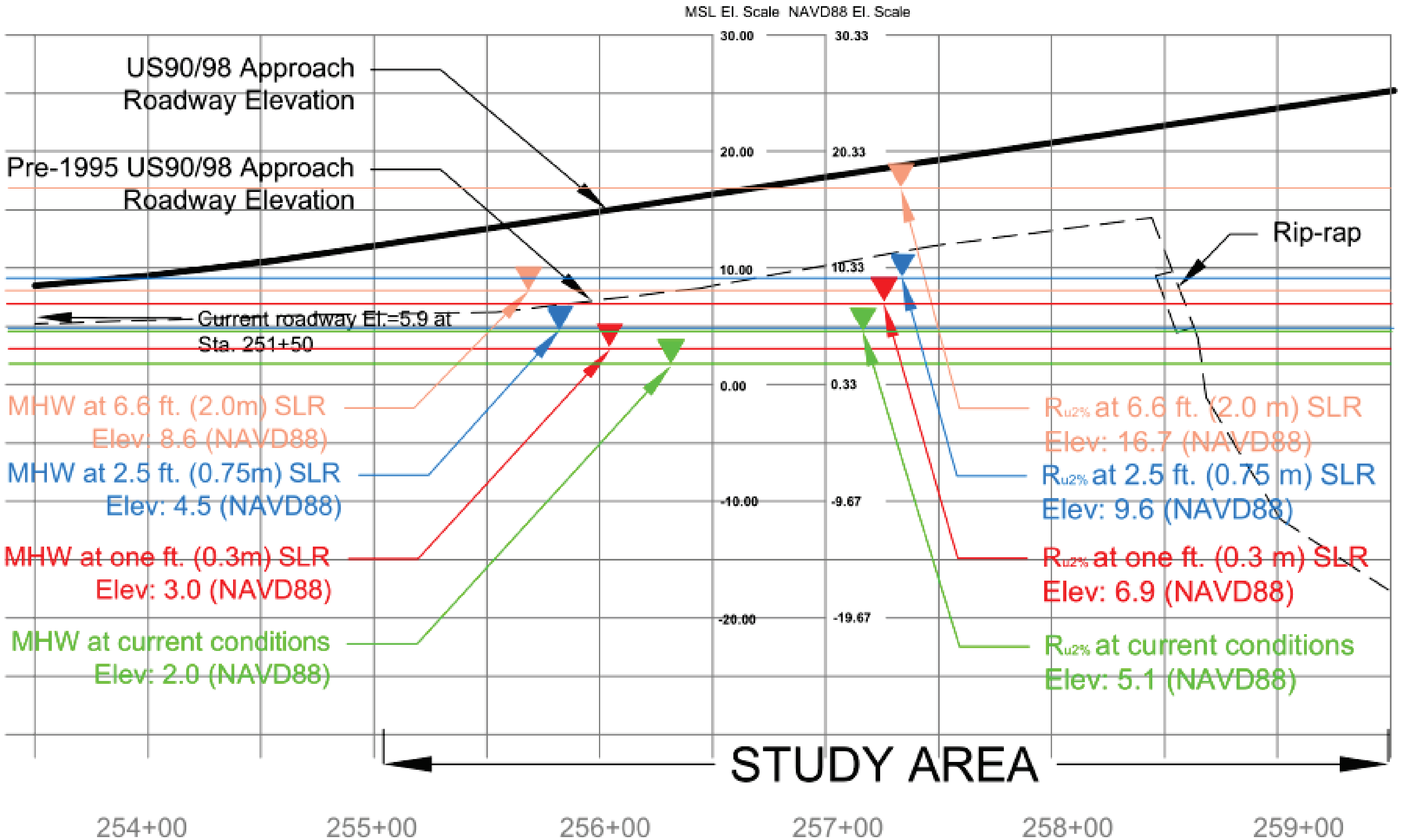


Figure 44: Profile of the US 90/98 Tensaw-Spanish River Bridge Approach Roadway and Western Embankment with MHW and 2% Run-up Water Levels[165]



[165] Source: ALDOT, 1994 (as modified). Note: All elevations shown refer to mean sea level. Mean sea level is the average of the water elevations recorded at each hour of the day over the current National Tidal Datum Epoch. The tidal epoch is the specific 19-year period over which NOAA uses to obtain observations that are used to develop tidal statistics.

Table 24: Summary of Revetment Riprap Size and Location Calculation Results at Western Approach Roadway to the US 90/98 Tensaw-Spanish River Bridge

Sea Level Rise	Medium Mass of Rocks, M_{50} Pounds (Kilograms)	Equivalent Cube Length of Rocks, D_{50} Inches (Meters)	Run-up ($R_{U2\%}$) Crest Elevation Feet (Meters)	Roadway Inundation Level
None	46 (21.0)	8 (0.2)	5.1 (1.5)	None
One foot (0.3 Meter)	121 (54.9)	11 (0.3)	6.9 (2.1)	Temporary from wave run-up
2.5 Foot (0.8 Meter)	340 (154.3)	15 (0.4)	9.6 (2.9)	Temporary from wave run-up
6.6 Foot (2.0 Meter)	1,971 (894.0)	27 (0.7)	16.7 (5.1)	Permanent from mean high water

As seen in Table 24, as sea levels rise and water depths in front of the embankment increase, the height of waves that can be sustained without breaking prior to impacting the embankment increase, consequently increasing the weight and dimensions of the riprap needed to protect against them. In addition, as the wave size increases, the height at which the run-up impacts the embankment and approach roadway increases as well.

It should be noted that although this case study provides an examination of the consequences that sea level rise will have on wind-generated wave heights and wave impacts to a bridge approach embankment, several other factors should be considered when analyzing potential threats to stability and functionality of a bridge approach in a tidal area. As previously mentioned, Section 4.4.4 provides a case study on the impacts of storm surge to bridge abutments, specifically, how flow velocities due to storm surges at a bridge abutment can cause scour impacts, and what adaptations should be made to respond to these impacts.

In addition, although this study looked only at the gradual impacts of a general sea level rise in association with climate change, the consequences of increased wave action due to storm surges should also be considered when analyzing wave impacts on embankments. It is very likely that wave heights that do not overtop the embankment in this case study may indeed overtop the roadway when considering storm surge impacts. In this case, there is a much higher risk of permanent loss of functionality of the roadway.

Step 6 – Identify Adaptation Option(s)

Under current conditions and the 2050 one foot (0.3 meter) and the 2100 2.5 feet (0.8 meter) sea level rise scenarios considered in this case study, the current riprap slope protection will provide adequate protection from wind-generated wave impacts if properly maintained. Under the 6.6

feet (two meter) seal level rise scenario, adaptations to protect the embankment slope and prevent water from accumulating on the western approach roadway would be required to maintain functionality of the existing bridge. To withstand wave run-up and impact under this scenario, placement of riprap slope protection at a size and elevation as shown in Table 24 would be required.

Under the 6.6 feet (two meter) seal level rise scenario, raising the height of the roadway will limit or eliminate the risk and impact of flooding along the bridge's western approach. Under the three sea level rise scenarios considered, the bridge itself was not overtopped but the approach roadway located west of the abutment was susceptible to flooding. Under the projected 2100 6.6 feet (two meter) sea level rise scenario, a portion of the embankment itself experiences overtopping. The following subsections provide specific adaptation options to meet the scenarios considered.

<u>Option 1 – Provide Maintenance to Ensure Proper Function of Existing Riprap Slope Protection</u>

Under this option, no substantive changes would be made to the existing riprap slope protection. The only action under this option would be to ensure that the coverage currently designed for the area of Class 3 riprap of a 3 foot (0.9 meter) thickness up to elevation 10.3 feet (3.1 meters) is properly maintained.

<u>Option 2 – Raising the Elevation of the Riprap Slope Protection, Approach Road, and Bridge</u>

The projected year 2100 6.6 foot (two meter) sea level rise scenario would require raising the roadway and seawall to an elevation of 16.7 feet (5.1 meters) so that it would not be susceptible to regular tidal elevations or overtopping with wave run-up heights. This option would involve armoring the embankment with Class 5, 28 inch (711 millimeter) minimum riprap slope protection to an elevation at or above 16.7 feet (5.1 meters) along the entire southern face of the west embankment. This armoring layer would consist of a 58 inch (1,420 millimeter) thick layer of stone with a D_{50} of 28 inches (711 millimeters), a 14 inch (356 millimeter) layer of 6 inch (152 millimeter) stone, and an impermeable geotextile fabric.

<u>Option 3 – Extending the Embankment Slopes</u>

Another option to address impacts from the projected year 2100 6.6 foot (two meter) sea level rise scenario would be to extend the slope of the embankment to decrease the amount of wave height and run-up exposure. To prevent roadway overtopping of waves, the angle of the embankment slope would need to be lessened to 2.9 degrees or 20 horizontal to 1 vertical. This would halt run-up at the same elevation of the upper limits of the existing riprap slope protection, 10.3 feet (3.1 meters). The embankment would extend approximately 225 feet (69 meters) further away from the roadway into the Bay. This option would involve armoring the embankment with Class 4, 22 inch (559 millimeter) minimum riprap slope protection to an elevation at or above 10.3 feet (3.1 meters) along the entire southern face of the west

embankment. This armoring layer would consist of a 44 inch (1,120 millimeter) thick layer of stone with a D_{50} of 22 inches (559 millimeters), an 11 inch (279 millimeter) layer of 5 inch (127 millimeter) stone, and an impermeable geotextile fabric.

It should be noted that any potential sea level rise issues on the embankment of the Tensaw-Spanish River Bridge will occur late in the design life of the bridge crossing. Given this, it might very well be the case that a full replacement of the existing bridge structure and approach roadways with a design that accounts for anticipated sea level changes will be a more cost-effective solution than retrofitting the existing structure.

Although not the focus of this case study, storm surge combined with sea level rise would need to be a consideration in any adaptive design. In the projected year 2100 6.6 feet (two meter) sea level rise scenario where wind-generated waves overtop the embankment and roadway completely, substantial protection would be needed to decrease the risk of damage to the roadway. In the case of the western approach to the Tensaw-Spanish River Bridge, significant surge combined with wind-generated wave impacts could potentially overtop the road. In this case, water can seep into the subgrade below the road surface and cause wave induced pressure penetration, which would dramatically increase the risk that the pavement is washed away and subgrade infrastructure (subbase material) is affected. In this case, more significant countermeasures would be required to mitigate this risk such as the installation of steel sheet piling. Other problems that can occur with roadway overtopping include wave induced slamming pressures caused by wave impacts to the underside of the bridge, where the abutment meets the bridge soffit (underside). Additional structural measures and protection could be required to ensure the integrity of the bridge structure in this location.

Step 7 – Assess Performance of the Adaptation Option(s)

Table 25 summarizes how well each of the proposed adaptation options performs under each of the storm surge scenarios. If these adaptation options actually were being considered for design, a full analysis quantifying the performance of each option under each scenario would need to be conducted and the results used in the economic analysis in Step 8.

Step 8 – Conduct an Economic Analysis

An economic analysis was not included in this case study but is recommended for facility-level adaptation assessments. See Section 4.4.1 for an example of how an economic analysis was applied to a culvert exposed to changes in precipitation due to climate change.

Table 25: US 90/98 Tensaw-Spanish River Bridge West Approach Embankment Adaption Performance Summary

Sea Level Rise	Impact Considered	Option 1	Option 2	Option 3
Current Conditions	Provides Embankment Protection	Yes	Yes	Yes
	Provides Overtopping Protection	Yes	Yes	Yes
	Type Of Inundation	None	None	None
Projected Year 2050 One foot (0.3 Meter) Sea Level Rise	Provides Embankment Protection	Yes	Yes	Yes
	Provides Overtopping Protection	Yes	Yes	Yes
	Type Of Inundation	Temporary	None	None
Projected Year 2100 2.5 Foot (0.8 Meter) Sea Level Rise	Provides Embankment Protection	Yes	Yes	Yes
	Provides Overtopping Protection	Yes	Yes	Yes
	Type Of Inundation	Temporary	None	None
Projected Year 2100 6.6 Foot (2.0 Meter) Sea Level Rise	Provides Embankment Protection	No	Yes	Yes
	Provides Overtopping Protection	No	Yes	Yes
	Type Of Inundation	Permanent	None	None

Step 9 – Evaluate Additional Decision-Making Considerations

Other important factors that might influence whether and how the approach roadway embankment is adapted to accommodate sea level rise include how land uses on Blakeley Island and the Causeway are impacted by sea level rise. If impacts are great enough to eliminate the need for vehicular access to these areas, then executing adaptations on both the I-10 roadway and the US 90/98 roadway may be redundant and unnecessary. In this case, it's possible that only one facility would be chosen and utilized in the future (likely I-10). The changing land uses may also have a significant impact on traffic volumes and the need for the bridge within the larger transportation network. In addition, there may be potential concerns with having a higher bridge adjacent to the USS Alabama Battleship Memorial Park, two ships in which are National Historic Landmarks. The entirety of the park is also on the Alabama Register of Landmarks and Heritage.

Step 10 – Select a Course of Action

As the facility currently meets design standards for riprap slope protection under current conditions as well as the 2050 one foot (0.3 meter) and the 2100 2.5 feet (0.75 meter) sea level rise scenarios, the recommended course of action is only to provide maintenance to ensure adequate protection along the embankment. It is advisable that the existing protection be inspected to ensure it meets the standard for a Class 3 riprap slope protection on an embankment to withstand the effects of wind-generated wave impacts under the project year 2100 2.5 foot (0.8 meter) sea level rise scenario. The 2100 2.5 foot (0.8 meter) sea level rise scenario is recommended because this is the most extreme scenario where permanent inundation of the

approach roadway does not occur under water level variations due to tides (an impact that would require additional actions). The existing Class 3 riprap slope protection along the length of the embankment and up to elevation 10.3 feet (3.1 meters) should provide adequate protection on the embankment if installed according to guidance from the *Coastal Engineer Manual* and HEC-25. Further study should be done along the entire approach roadway to determine the impacts of sea level rise on the approach roadway further from the bridge than was considered in this study. In addition, storm surges under which the embankment and approach roadway may be exposed should be considered as well.

Regarding the elevation of the road itself, as sea level rise is a relatively gradual phenomenon (even considering its projected acceleration after mid-century), monitoring over time will allow for evaluation of actual sea level rise trends. If trends point to the likely occurrence of a more extreme sea level rise scenario that could cause temporary or permanent inundation of the approach roadway, appropriate actions should be taken to begin the process of raising the embankment and approach roadway or altering the embankment slope to protect against tidal and wave run-up influences.

Step 11 – Plan and Conduct Ongoing Activities

The recommended ongoing activity is to monitor actual trends in observed sea level in the Mobile region and compare them to the projected sea level rise scenarios with the goal of ascertaining what scenario is being realized. A "trigger level" of sea level change might be established (based on the sea level rise curves and the projected time required to plan, design, finance, and construct a chosen adaptation option) at some point prior to the development of conditions that could cause wave run-up that overtops the roadway along the embankment. When the trigger level is crossed, planning and financing activities for adapting the facility can then commence.

Conclusions

This case study has, using the *General Process for Transportation Facility Adaptation Assessments*, demonstrated how sea level rise effects on wind-generated wave heights and wave impacts can be analyzed for an approach roadway embankment. Protection and risk reduction measures for the US 90/98 Tensaw-Spanish River Bridge west approach embankment would be necessary for each of the climate scenarios tested. An adaptation concept was developed for each scenario whereby the roadway, approach roadway, and abutment would need to be raised to a height that would significantly reduce the risk of overtopping from wave run-up. Information must be shared with local stakeholders and discussed before any locally preferred decisions can be made on what adaptive actions (if any) would be appropriate for raising the road / bridge and when would be the best time to implement them.

The process shown is broadly applicable to roadway embankments across the country where sea level rise and wind-generated waves have an influence. Embankments with susceptibility to

wind-generated waves would need to be investigated for potential instability and wave overtopping due to sea level rise to determine if any adaptive action would need to be implemented. Ultimately, this effort is best handled at a planning level in a coordinated manner amongst all embankments along a roadway to ensure that functionality is maintained at all susceptible points. It is recommended that such analyses be undertaken for bridge embankments across the country that are subject to sea level rise and wind-generated wave impacts.

4.4.4 Bridge Abutment Exposure to Storm Surge – US 90/98 Tensaw-Spanish River Bridge (Western Abutment)

Introduction

More powerful storm surges resulting from higher sea levels and stronger hurricanes represent potentially serious threats to coastal bridges. One of these threats is the weakening and potential failure of bridge abutments, critical components of a bridge structure and the primary means of retaining the soil supporting the approach roadway's embankment. Bridge scour is the erosion of the soil surrounding bridge abutments caused by fast flowing water (see Figure 45 for an example of severe abutment scour). Loss of the supporting soil can cause structural instability, shifting of key support structures, and the actual collapse of a bridge. This case study analyzes the potential for scouring of the west abutment of the US 90/98 bridge over the mouths of the Tensaw and Spanish Rivers and the adequacy of the existing rock riprap scour protection measure. Other sections of this report provide case studies of climate impacts to different bridge components such as sea level rise effects on approach embankments (see Section 4.4.3) and storm surge effects on piers and decks (see Section 4.4.5).

Case Study Highlights

Purpose: Evaluate whether a bridge abutment is vulnerable to potential storm surges

Approach: Using the NCHRP 24-20 Abutment Scour Approach, the estimated scour depth and elevations for three storm surge scenarios were determined. Then, the scour protection that would be provided by the protective structures in place (riprap, bulkhead, and willow mattress pads) was evaluated.

Findings: Although on its own the bridge abutment might be vulnerable to the surges, sufficient protective features are in place that will this particular abutment is likely not vulnerable to the surges studied

Viable Adaptation Options (for other, vulnerable sites):

- Widen or lengthen the bridge
- Armor the bridge opening
- Control drainage to avoid erosion in the abutment area
- Control water flow to minimize erosion

Other Conclusions: Protective features like riprap and willow mats play an important role in the ability of an asset to withstand surge—even if the asset itself appears to be on dry ground. It is vital that inspectors look at the whole picture when inspecting assets.

Formulas for estimating scour are very conservative, leading agencies to protect foundations rather than design the foundations to resist scour.

Figure 45: Example of Severe Scour at a Bridge Abutment[166]

The bridge abutment analysis was conducted using the 11 step *General Process for Transportation Facility Adaptation Assessments*, which serves as the organizing framework for this case study. The assessment determined that none of the storm surge scenarios studied presented a threat to the integrity of the abutment and, as a result, no adaptation options are recommended at this time.

Application of the General Process for Transportation Facility Adaptation Assessments

Step 1 – Describe the Site Context

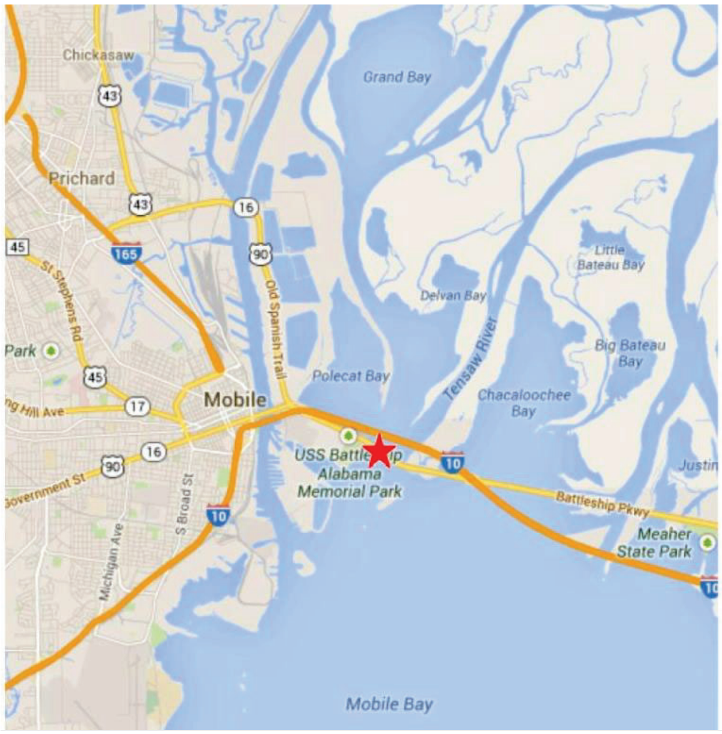
The bridge abutment case study was developed for the west abutment of the US 90/98 (Battleship Parkway) bridge over the mouths of the Tensaw and Spanish Rivers (The Tensaw-Spanish River Bridge). This is the same facility studied for sea level rise impacts to the approach embankments in Section 4.4.3 of this report. The eastbound and westbound bridge abutments are situated 12 feet (3.7 meters) apart (edge-to-edge) and have the same orientation, elevations, and distance from the mean water line. As such, the abutments are considered as a single unit for this study and the resulting scour depths and protections discussed herein can be considered applicable to either the westbound or eastbound abutment.

As noted in Section 4.4.3 , the bridge provides an alternative crossing of Mobile Bay in case the I-10 (Jubilee Parkway) bridge (the "Bayway") is closed. US 90/98 also serves as the access road for nearby areas including several commercial businesses and the USS Alabama Battleship

[166] Arneson, Zevenbergen, Lagasse, and Clopper, 2012.

Memorial Park, which is located just southwest of the study site. See Figure 46 for a map showing the location of the case study bridge within the Mobile region.

Figure 46: Location of the US 90/98 Tensaw-Spanish River Bridge within the Mobile Metropolitan Area[167]

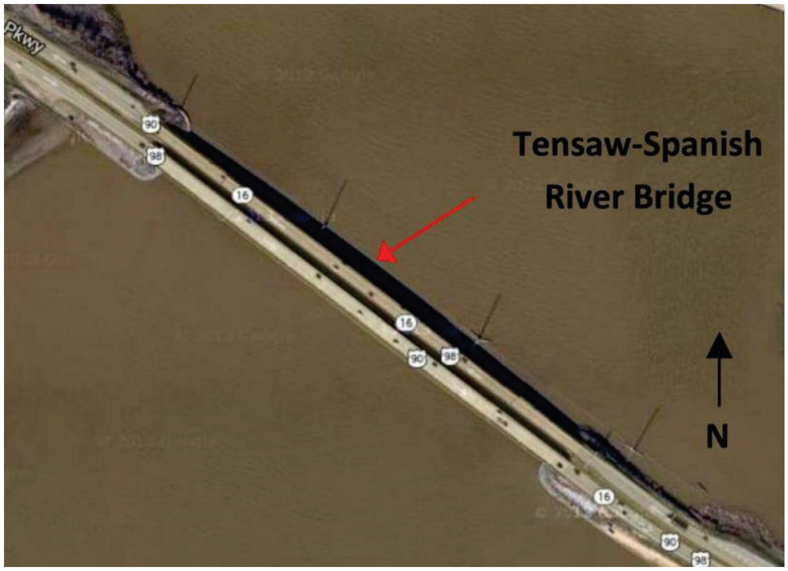


Step 2 – Describe the Existing Facility

As shown in the aerial photograph in Figure 47, the Tensaw-Spanish River Bridge consists of two parallel bridge crossings: a northern span for westbound traffic and a southern span for eastbound traffic. The northern span was designed in 1963 and has steel girders,[168] whereas the southern span was added in 1995 and utilized pre-stressed[169] concrete girders. Both spans have 10 in-water piers with spacing varied between 125 feet to 140 feet (38.1 to 42.7 meters) apart. Figure 48 provides plan and profile views of the pier configurations and plan details of the southern (eastbound) span.

[167] Source of basemap: Google Maps (as modified)
[168] Girders are the main horizontal supporting members of the bridge.
[169] Pre-stressed construction involves the process of applying tension to the longitudinal steel rebar reinforcement inside a concrete unit during the manufacturing process.

Figure 47: Aerial Image of the US 90/98 Tensaw-Spanish River Bridge[170]

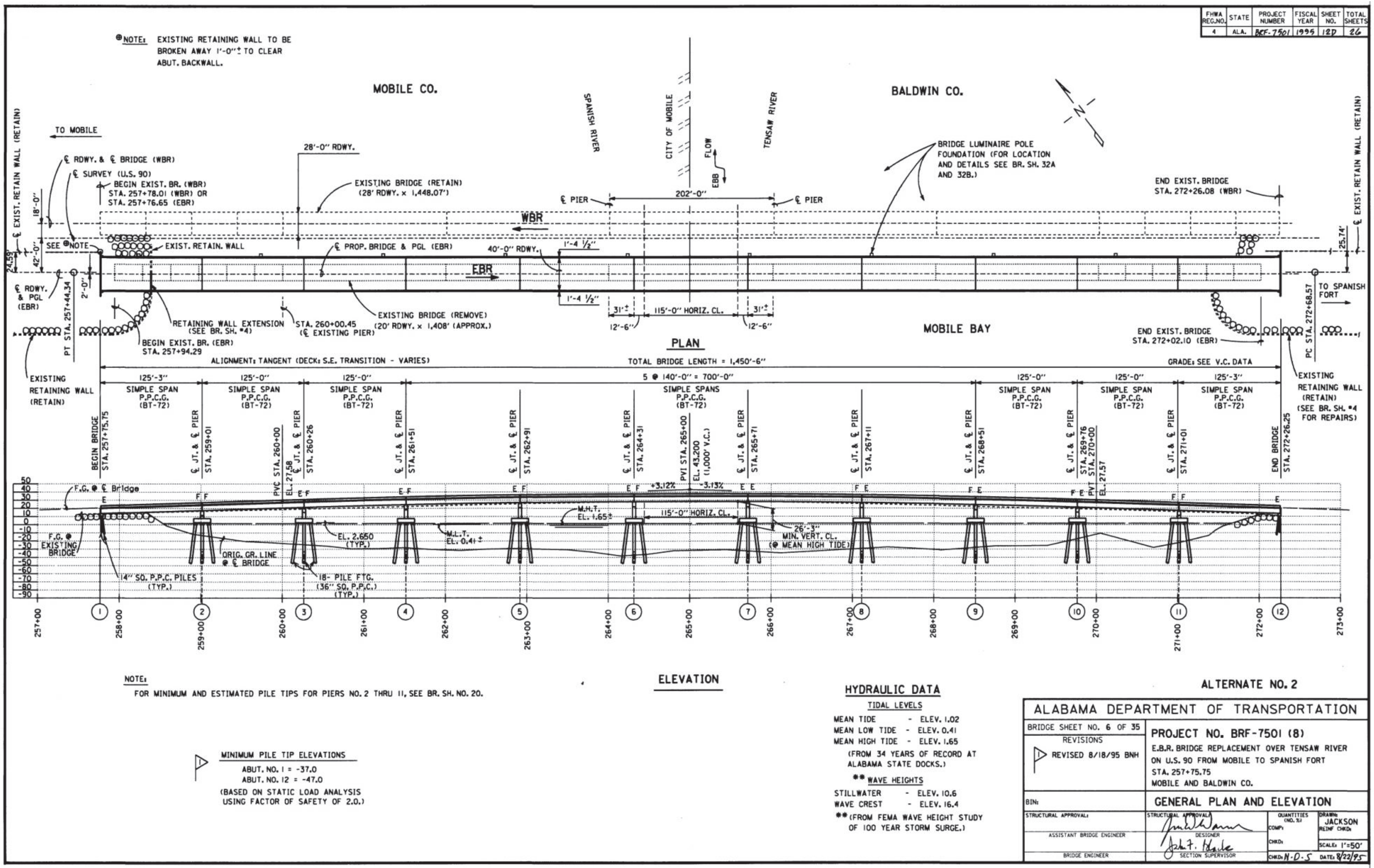


The bridge abutments are a pile-supported concrete design as detailed in Figure 49 and Figure 50. The abutment is supported by 14 inch (35.6 centimeter) square pre-stressed concrete piles as shown on Figure 49. The pile tip bottoms were designed to be driven down to an elevation of -17.7 feet (-5.4 meters).[171]

The abutments are armored against scour by three different design features: a willow mattress,[172] a bulkhead, and stone riprap.[173] The three features work in unison with the goal of providing complete armoring to the bridge abutment and supporting soils. A section view showing the riprap, the timber bulkhead, and the willow mattress and their relation to the west bridge abutments is presented in Figure 51.

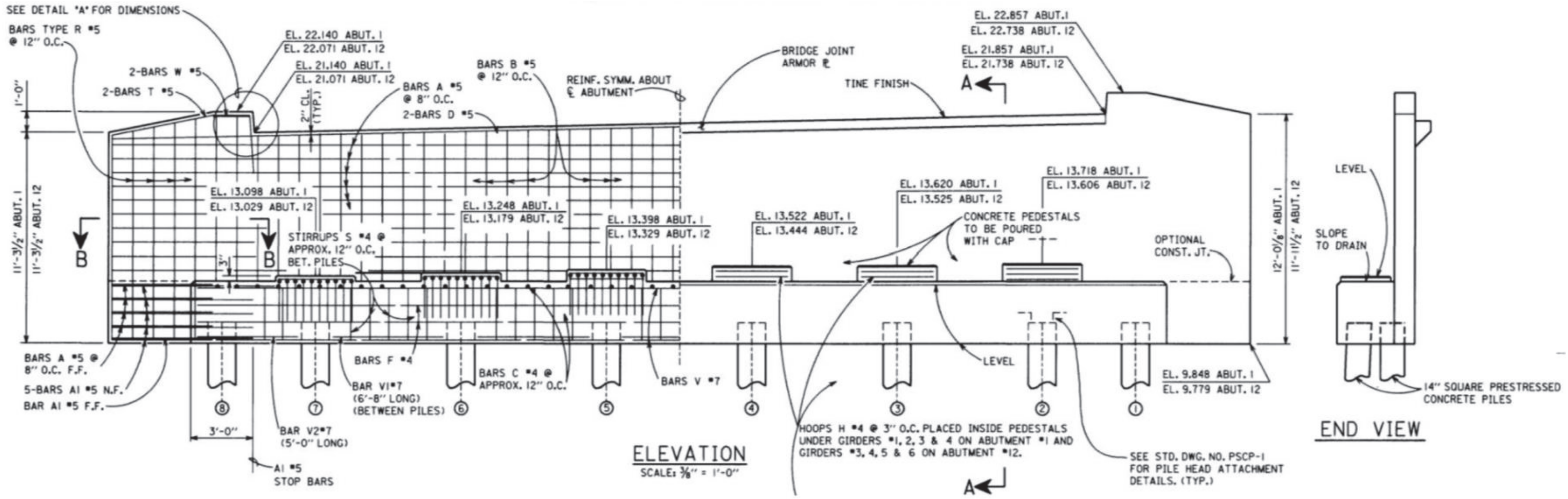
[170] Source of aerial image: Google Maps (as modified)
[171] All elevations in the text of this report are with respect to the North American Vertical Datum of 1988 (NAVD88)
[172] A willow mattress is an interwoven series of willow branch cuttings, joined to form a contiguous semi-rigid mattress.
[173] Riprap consists of loose stone placed in a manner to provide erosion protection or armoring over a soil area.

Figure 48: Plan and Elevation of the US 90/98 Tensaw-Spanish River Bridge Southern (Eastbound) Span[174]



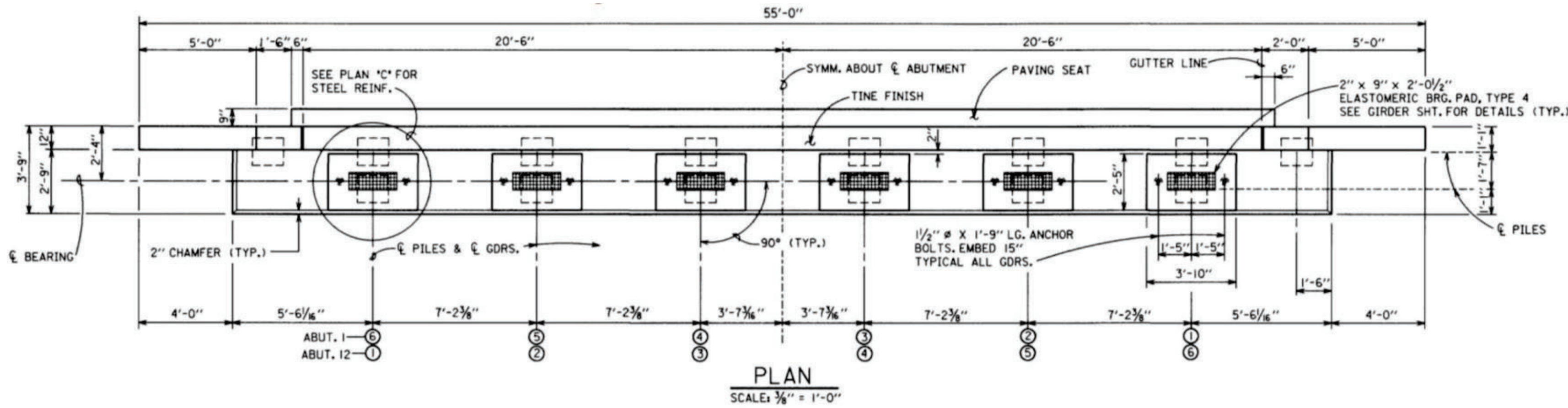
[174] ALDOT, 1994

Figure 49: Western Abutment of the US 90/98 Tensaw-Spanish River Bridge Front Elevation Detail[175]



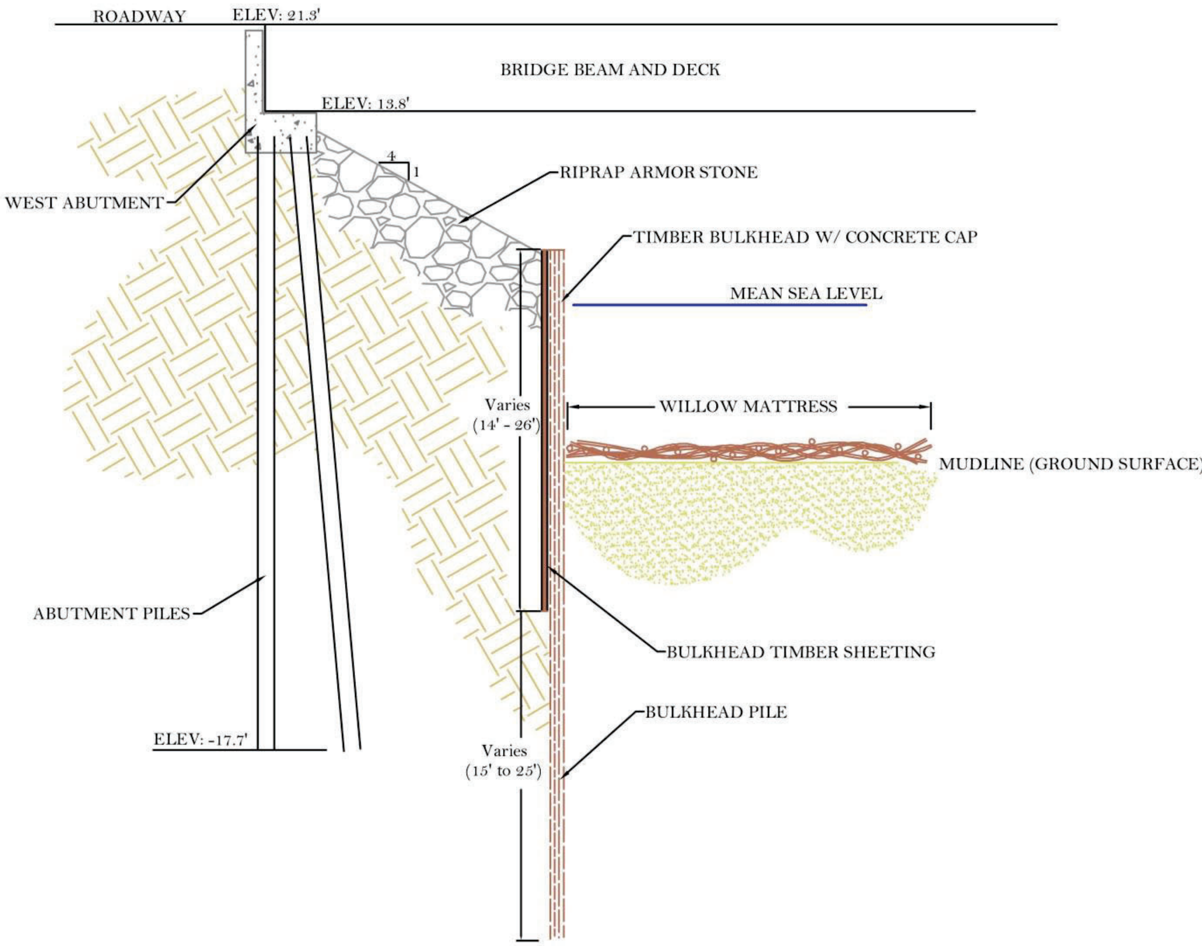
[175] ALDOT, 1994

Figure 50: Western Abutment of the US 90/98 Tensaw-Spanish River Bridge Plan View Detail[176]



[176] ALDOT, 1994

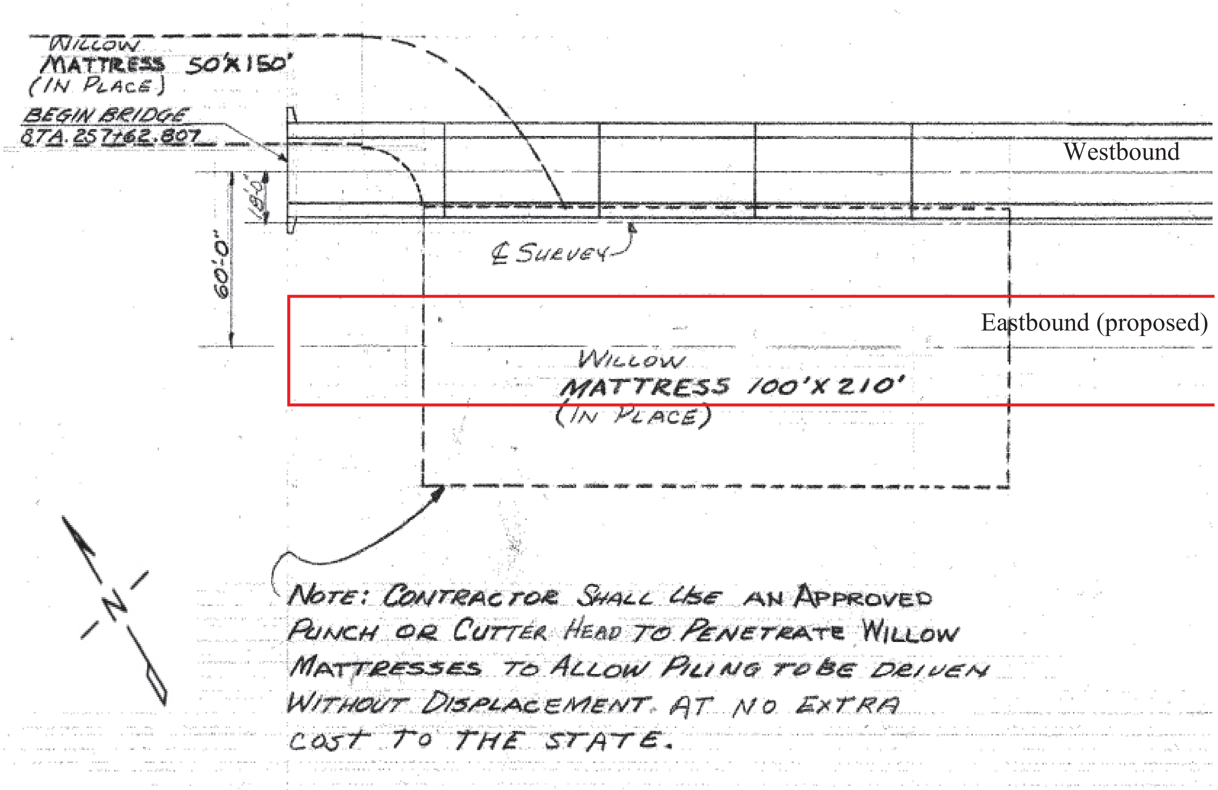
Figure 51: Typical Section View of the West Abutments of the US 90/98 Tensaw-Spanish River Bridge Showing the Scour Countermeasure Protections.[177]



Willow mattress mats were included in the 1963 plans to stabilize the river bottom around the abutment. The 1963 plan showing the locations of these protections is shown in Figure 52. Figure 52 has been modified to show the approximate alignment of the eastbound bridge span, which was not included in the original drawing set. An example of a willow mattress mat being installed is shown in Figure 53. The mattress pads are sunk into place and weighted down using large rock or sections of demolished pavement. Plans for the willow mattress mat show a 100 foot wide by 210 foot long (30.5 meter wide by 64 meter long) mattress that is roughly centered along the alignment of the southern bridge span. In addition, a 50 by 150 foot (15.2 by 45.7 meter) willow mattress also wraps around the north side of the abutment. Construction plans for the southern bridge note that a cutting of the mattress was necessary for the new bridge construction in 1994.

[177] Sketch is not to scale and elevations as shown are approximate.

Figure 52: Plan for the Location of the Willow Mattress Pads at the US 90/98 Tensaw-Spanish River Bridge[178]



[178] Source: Highway Department of Alabama, 1963 (as modified). Note: The plan shows only the northern (westbound) span because, as noted previously, the southern (eastbound) span was not part of the original bridge project. Lines have been added showing the approximate location of the eastbound span.

Figure 53: Representative Willow Mattress Pad (Assembly Prior to Submergence)[179]

In Figure 52 note that no information is presented regarding protection along the southern side of the abutment. It is unclear if there exists no protection in this area or if the 50 by 150 foot (15.2 by 45.7 meter) willow mattress marked along the north side of the abutment extends down into this area and was just not included in this drawing. The current study only considers the typical protection section (as shown in Figure 51). Future detailed evaluations of this bridge abutment are recommended to include further research into the coverage and condition of the willow mattresses. In the event that either the southern side of the abutments is not protected or if any portion of the mattress has significantly degraded, the conclusions of the study may be impacted due to the development of scour at a weak point in the system not currently under consideration.

Along with the willow mattresses, a concrete and timber bulkhead protects the southern side of the western bridge abutments and approach roadway. The bulkhead, in this case, is a timber construction coastal retaining wall which extends vertically from a specified depth below the sea floor up to an elevation of approximately 5.5 feet (1.7 meters). Bulkheads in a coastal setting are also commonly referred to as seawalls and are employed to resist coastline erosion, or in this case, storm induced scouring of the roadway approach and bridge abutment. The bulkhead at the US 90/98 Tensaw-Spanish River Bridge consists of timber planks 20 to 26 feet (6.1 to 7.9 meters) long supported by 30 to 40 foot (9.1 to 12.2 meter) vertical timber piles spaced nine feet (2.7 meters) apart. The sheeting and piles are labeled on Figure 51 and an example can be seen in the typical timber bulkhead shown in Figure 54 below. Although 50 years into its design life, aerial imagery indicates the US 90/98 Tensaw-Spanish River Bridge Bulkhead appears to be in

[179] Legasse, Clopper, Schall, and Zevenbergen , 2001

generally sound condition. Although not shown on the available construction plans, a continuous concrete cap was added to the top of the timber structure.

Figure 54: Example of Typical Timber Bulkhead Protection at a Highway Bridge Abutment[180]

Complementing the bulkhead, rock riprap protection armors the slopes above it. This rock riprap protection is the same protection that is evaluated in section 4.4.3 of this report with respect to sea level rise. Review of site photos indicates that the riprap is approximately 15 to 18 inches (38.1 to 45.7 centimeters) in size. The riprap is generally situated on a four horizontal to one vertical slope and has a design depth of three feet.[181] From inspection of available imagery, the sizing is estimated as a Class 3 riprap according to the ALDOT classification system (see Table 26). The riprap coverage displays a significant amount of soil interspersed amongst the rocks. The visible soil interspersed among the rocks could have occurred due to either wind / water borne deposition of sediments or due to dislodging / movement of the riprap. Some bare earth was also observed in historical photos under the bridge adjacent to the abutments, which may indicate some local erosion occurring along the roadway embankments. Future studies of the bridge protection are recommended to include a detailed inspection of the riprap, including determination of the coverage limits and quality of the rock placements, to ensure that no degradation and formation of failure points is developing. The current study assumes that the rock protection has maintained the as-built condition and that the visible soil is due to deposition and not degradation of the rock protection.

[180] Photo of the Mullica River Bridge, New Jersey (taken in 2006).
[181] ALDOT, 1994

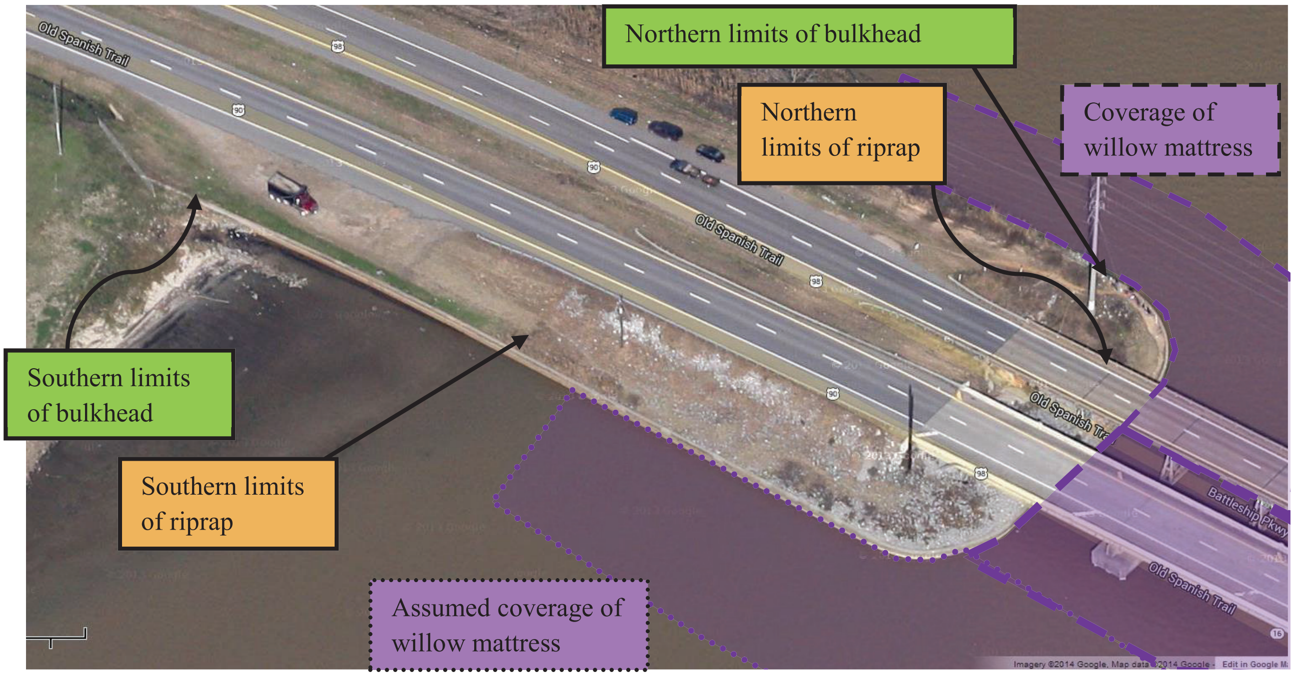
Table 26: ALDOT Standard Riprap Classes[182]

Riprap Class	Weight Range – D_{10}[183] to D_{90} Pounds (Kilograms)	D_{50} Size	
		Pounds (kgs)	Inches (mm)
1	10 – 100 (4.5 – 45)	50 (22.7)	10 (254)
2	10 – 200 (4.5 – 90.0)	80 (36.3)	12 (305)
3	25 – 500 (11.3 – 226.8)	200 (90.7)	15 (381)
4	50 – 1,000 (22.7 – 453.6)	500 (226.8)	22 (559)
5	200 – 2,000 (90.7 – 907.2)	1,000 (453.6)	28 (711)

Figure 55 shows the limits of each of the three scour countermeasure protections overlain on an aerial image of the bridge abutment. In Figure 55, the approximate layout of the willow mattress is shown, including the assumption that the willow mattress was placed to cover the southern side of the approach roadway / abutment.

[182] ALDOT, 2012
[183] Dx denotes rock gradation percentages for which the distribution of individual stones will have diameters of X percentage of the sample batch smaller than the stated measurement value. For example, for D_{50} = 10 inches (254 millimeters), 50% of the rocks in the batch will have diameters smaller than 10 inches (254 millimeters) and 50% will have diameters greater than 10 inches (254 millimeters).

Figure 55: Aerial view of the Tensaw-Spanish River Bridge West Abutment Showing the Limits of Scour Protections[184]



The condition of the various protective design features on the abutment are a key determinant in how effectively they might perform during a storm. In the development of this study, ALDOT underwater inspection records[185] from various timeframes were investigated to determine the conditions of the abutment protection measures, however, in general the inspectors classified the abutments as being "dry" and no additional investigations were performed in these areas. Future studies should investigate the condition of the various protection measures through field inspections (this work was beyond the scope of this case study).

Step 3 – Identify Climate Stressors That May Impact Infrastructure Components

Coastal storm surge on top of sea level rise is the primary climate change-related environmental factor of concern to abutment design. Other climate change considerations that are not included in this study but which may be relevant in more inland riverine settings include precipitation changes and associated changes in riverine flooding.

Step 4 – Decide on Climate Scenarios and Determine the Magnitude of Changes

Design standards for coastal infrastructure such as the Tensaw-Spanish River Bridge typically specify acceptable return periods (e.g., the 100-year storm) for which water is not allowed to overtop facilities or reach other pre-specified thresholds. This section will therefore begin with a detailed discussion of storm surge return periods in the context of a changing climate and some

[184] Source of aerial image: Google Maps (as modified)
[185] ALDOT, (various dates)

of the difficulties associated with their computation. Then, given the difficulties in accurately computing future storm surge return periods with climate change, an alternative approach to considering surge in the context of a changing climate is presented and used in this case study.

In order to account for the effects of climate change on a particular design event like the 100-year base flood elevation there is a wide range of long term changes to the region that need to be considered. For the nearshore areas of Mobile County, adjacent to the coast and bay, the FEMA 100-year base flood elevation is based on the elevation of the wave crest and thus accounts for both the hurricane induced storm surges and associated wave conditions. Over the following decades it is possible climate change may affect several aspects of the regional topography, bathymetry, and land surface cover or use. For example, sea level rise may alter sedimentation patterns within the bay; may drown existing marshes unless sedimentation rates are able to keep up with rising sea level; and land use may change along the shoreline resulting in modified land cover as well as re-locations of levees, roads and other assets which may affect local flooding conditions. Regional changes in land topography and bathymetry as well as land cover and use have the potential to alter the flood levels (surge plus wave crest) for a given future hurricane event. The long range prediction of these changes is highly uncertain. In addition, land use change may not occur until a catastrophic event forces change (for example, if limited resources or other reasons preclude re-establishment of a structure at its previous location).

How can one adjust 100-year coastal floodplains to accurately account for climate change? The update process for present-day flood mapping provides a starting point for understanding what would be involved. At the time of publication, several regions along the U.S. East and Gulf Coasts are undergoing significant analyses and updates to their FEMA flood insurance studies. An example is the work being performed in the New York and New Jersey area.[186] These flood insurance studies typically include analyses of hundreds if not thousands of hurricane scenarios including historic hurricanes as well as synthetic variations of these historic events.[187]

The most accurate methods of accounting for sea level rise impacts on surge return would be to use an approach similar to the one used in the FEMA updates but, in addition, analyze the set of hurricanes combined with various relative sea level rise scenarios. This would allow incorporation of sea level rise in the results so the resulting recurrence interval events (e.g., the 50-year, 100-year and 500 year) include sea level rise as well as its effect on hurricane surge and waves. In addition, other effects such as increasing storm intensity could be analyzed by accounting for this effect on the storms and using these enhanced storms in the hurricane surge and wave modeling. In areas where drainage of inland floodwaters is impeded by elevated water levels due to surge, the impact of heavier precipitation due to climate change could also be analyzed. However these are significant efforts and will not likely be undertaken as part of

[186] FEMA, 2013a
[187] Synthetic variations of storms are created by altering many variables such as central pressure, forward speed of the storm, landfall location and storm radius.

isolated transportation related planning, repair, or capital projects. Each of these regional flood insurance study updates is a multi-million dollar program that includes:

- Development of a topographic and bathymetric terrain model
- Consideration of the local and regional hurricane history
- Assessment of historical storms for primary parameters that define a particular storm (e.g., storm path, pressure deficit, radius to maximum wind, forward speed of storm, and storm track)
- Choice of a subset of these storms for analysis. The subset is carefully selected to yield a set of hurricanes that capture the general behavior of historic storms.
- Development of synthetic versions of the selected storms to create a wide array of possible storm scenarios by altering the primary storm parameters mentioned above. An example of this is shown in the currently effective Flood Insurance Study (FIS) for Mobile County.[188]
- Assessment of the probability of occurrence for each storm
- Running of each of the synthetic storms (as well as the actual event for the selected storms) with a hurricane modeling system such as the ADvanced CIRCulation model (ADCIRC) and STeady State spectral WAVE model (STWAVE) (the combination used in this study) or, alternatively, ADCIRC coupled with the Simulating WAves Nearshore model (SWAN),[189] another commonly used wave transformation model.
- Noting the model outputs of interest (e.g., wind speeds, water levels, currents, waves)
- Analyzing the hurricane input parameters, probabilities, and model outputs to yield the resulting probability of occurrence (i.e., average annual return interval) as a function of the output parameter of interest (e.g., storm surge, wave height)
- Considering additional flooding aspects beyond the tropical storms mentioned above (e.g., extra-tropical storms, tsunamis)

Given the time and expense associated with an analysis of this type, alternative approaches must be considered to provide surge levels for individual projects that aim to consider sea level rise and surge. The approach taken to develop storm surge scenarios for this study provides one example. Instead of a full scale statistical analysis to develop return period storms, a more limited number of model runs were executed to explore the range of possible impacts in the context of historic storm events that local stakeholders were familiar with. The three storm surge scenarios that were developed for this analysis include:

- Hurricane Katrina Base Case Scenario
- Hurricane Katrina Shifted Scenario
- Hurricane Katrina Shifted + Intensified + Sea Level Rise (SLR) Scenario

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[188] FEMA, 2010d
[189] Dietrich, Tanaka, Westerink, Dawson, Luettich, and Zijelma, Holthuijsen, Smith, Westerink, and Westerink, 2012

Hurricane Katrina was selected as the base case due to its impacts on the study area and its recent occurrence in 2005 resulting in significant observations and modern data collection of meteorological and oceanographic effects such as pressure deficit, wind, storm track, water level, waves, etc. In addition, this event is the most recent hurricane involving significant storm surge, wind, and waves for residents and transportation stakeholders in the Mobile area. As such it represents an actual event allowing residents and stakeholders a point of reference relative to the additional surge scenarios developed for this study involving an altered storm path and climate change.

For the second surge scenario, the path of Katrina was shifted for a direct hit on Mobile using current sea level and climate conditions. This shifted storm scenario recognizes the accepted practice in hurricane simulation and FEMA Flood Insurance Studies that historic storm landfall locations are assumed to be statistically as equally likely to have made landfall anywhere within the local coastal area.

The third scenario is the shifted Katrina that has been intensified with a reduction in atmospheric pressure resulting in higher wind speeds. This scenario also incorporates an intermediate long term increase in global sea level of 2.5 feet (0.8 meters).[190] This scenario is used in this adaptation assessment to identify impacts associated with possible future climate changes during the latter half of the 21st century.

Simulations of storm-induced water levels (i.e., storm surge) and associated currents were performed for each scenario using the two dimensional depth average version of the ADvanced CIRCulation model, ADCIRC. While the ADCIRC model is capable of applying a variety of internal and external forcings (including tidal forces and harmonics,[191] inflow boundary conditions,[192] density stratification,[193] and wave radiation stresses[194]), only the meteorological forcing[195] input was used to drive the storm-induced flows and water levels for this study. In some circumstances, effects such as elevated stream or river inflow due to previous storms or a particularly wet season may exacerbate flood levels when interacting with storm surge. Numerical models such as ADCIRC can account for this type of situation provided the streamflows are included as part of the hydrodynamic model input.

[190] See Section 4.4.3 for a discussion of the sea level rise scenarios used in this report

[191] A harmonic is a tide wave with a given frequency and amplitude

[192] Inflow boundary conditions are specified when flow conditions are known at the model boundary (e.g., in an estuary, an inflow boundary condition may be specified where a significant stream or river enters the model)

[193] Density stratification may be due to temperature or salinity variation in space. A salinity wedge is an example of a density stratification induced effect where the more saline (heavier) water will tend to flow below the less saline (lighter) water resulting in a density driven current. The salinity difference between the two sources of water is mixed across this interface.

[194] Wave radiation stresses occur where there is variability in the wave conditions from one location to another. For example, in the surf zone the rapid variation of wave height leads to wave radiation stress variation across the surf zone with induced wave setup (a superelevation of water level in the vicinity of the shoreline above the prevailing still water level) and wave induced currents.

[195] Meteorological forcing used in the ADCIRC modeling consisted of a time history of the following data: the latitude and longitude of the hurricane eye, the maximum observed wind speed, the minimum sea level pressure, and the radius from the center of the storm to a specified wind intensity. For further detail the reader is referred to USDOT, 2012.

The wave characteristics accompanying each of the storm surge scenarios were simulated using the STeady State spectral WAVE (STWAVE) model. STWAVE is a flexible, robust model for nearshore wind-wave growth and propagation. It is a steady-state,[196] finite difference,[197] spectral model[198] based on the wave action balance equation. STWAVE simulates depth-induced wave refraction[199] and shoaling,[200] current-induced refraction[201] and shoaling, depth- and steepness-induced wave breaking, diffraction,[202] wave growth based on wind input, and wave-wave interaction and white capping that redistribute and dissipate energy in a growing wave field. Recent upgrades to the model include wave-current interaction and steepness-induced wave breaking. More details on the development of each of the surge scenarios and wave modeling can be found in the *Climate Variability and Change in Mobile, Alabama* report.[203]

With respect to this case study, the model generated outputs for storm surge elevations, flow velocities, and water depths that were collected at five points of analysis (see Figure 56). The points were chosen to represent the peak near abutment conditions (points A and B), average mid-span conditions (point C), the representative approach flood tide (point E), and the representative approach ebb tide (D) conditions. These points were chosen using sound engineering judgment to represent the bridge hydraulics for use in the abutment scour prediction. The selection of the points is intended to be consistent with the hydraulic conditions utilized in the development of the abutment scour equations. While each of these reported points did not ultimately factor into the final computations, they were chosen as important considerations in the understanding of flow conditions around the bridge and the conditions that produced the maximum scour.

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[196] Steady-state implies there is no variation with time. The STWAVE model is run with a single representation of the wind field and offshore wave condition at a single point in time. With this input data STWAVE calculates wave conditions within the modeled area under the given steady-state condition.
[197] Finite-difference indicates the model grid is a series of rectangles and these are typically uniform across the model area. This is in contrast to model grid that can accommodate variation of the model elements in space (such as the finite-element ADCIRC model where, through the use of triangular cells, the size can be altered for model performance improvement such as large cells in the deep ocean and smaller cells nearshore or where higher resolution is needed).
[198] A spectral model indicates the book-keeping for nearshore wave transformation effects is done with a wave spectrum which is a representation of a random wind wave field as a series of sine waves of varying amplitude, direction, and frequency. For additional detail the reader is referred to USACE, 2002.
[199] Wave refraction can alter a wave field due to wave speed modifications that are not uniform in space. Due to variable bathymetry and associated water depths, the wave speed decreases with deceasing depth. Thus, around a headland, wave refraction will focus the wave resulting in increased wave heights. In curved embayments, the wave form will spread out resulting in decreased wave heights.
[200] Wave shoaling results from decreasing wave propagation speed and wave length as a wave advances into shallower water. This effect tends to steepen the wave due to shorter wave lengths and higher wave heights (USACE, 2002).
[201] Another important wave refraction effect is currents that vary in space. A wave entering a region with an opposing current will steepen and may undergo other changes such as altered propagation direction or reduced wave length (USACE, 2002). At the mouths of rivers (known as bars) on the coastline, opposing currents during ebb tide will steepen the oncoming ocean waves, due to smaller wave lengths and higher wave heights, resulting in more hazardous navigation conditions.
[202] Wave diffraction results in wave energy being spread laterally (i.e. perpendicular to the wave propagation direction). This effect is commonly seen behind breakwaters where the advancing wave crest is blocked by an obstruction creating a shadow area behind the structure that is sheltered from the oncoming waves. The wave diffraction process results in wave energy spreading laterally from the undisturbed wave crests into the sheltered area. The result is the classic semi-circular wave pattern of decreasing wave height behind the breakwater that can sometimes be seen in aerial photos (USACE, 2002).
[203] USDOT, 2012 (Section 7)

Figure 56: Aerial Image of the US 90/98 Tensaw-Spanish River Bridge Showing the Five Points of ADCIRC-STWAVE Analysis[204]

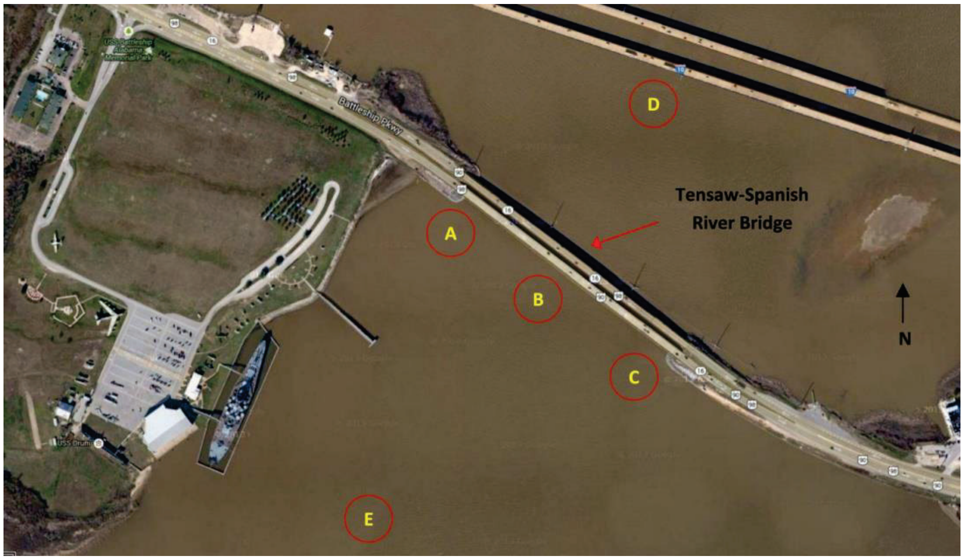
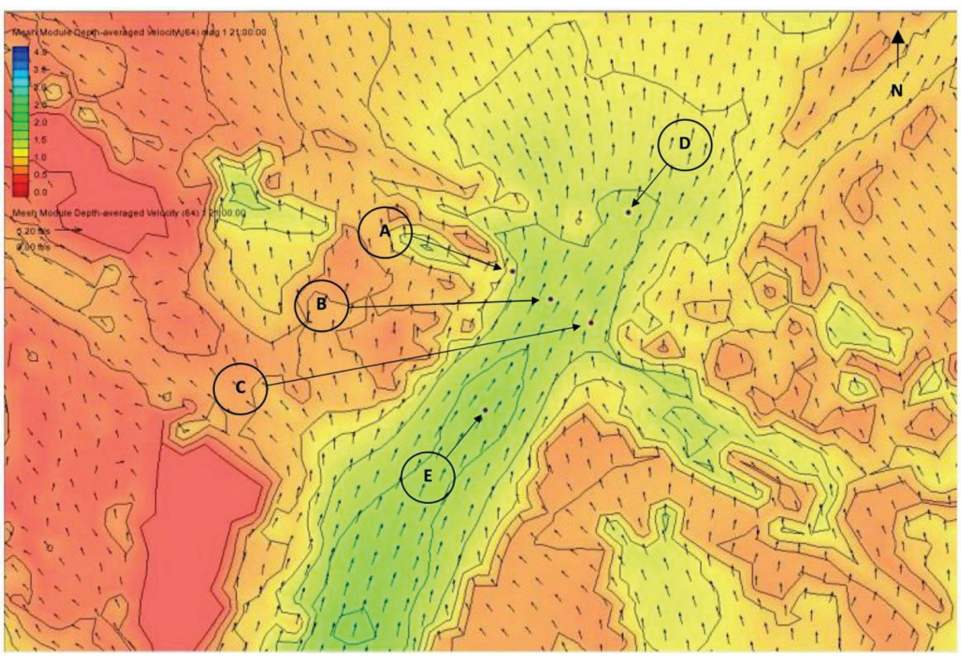


Figure 57 depicts the surge flow vectors from the model during a storm surge condition in relation to the five data points in Figure 56. The total depth of water at a point of analysis is arrived at by totaling the water elevation and the river mudline[205] elevations. The vectors shown in the image have been interpolated from the ADCIRC model and are not representative of the computation points in the model.

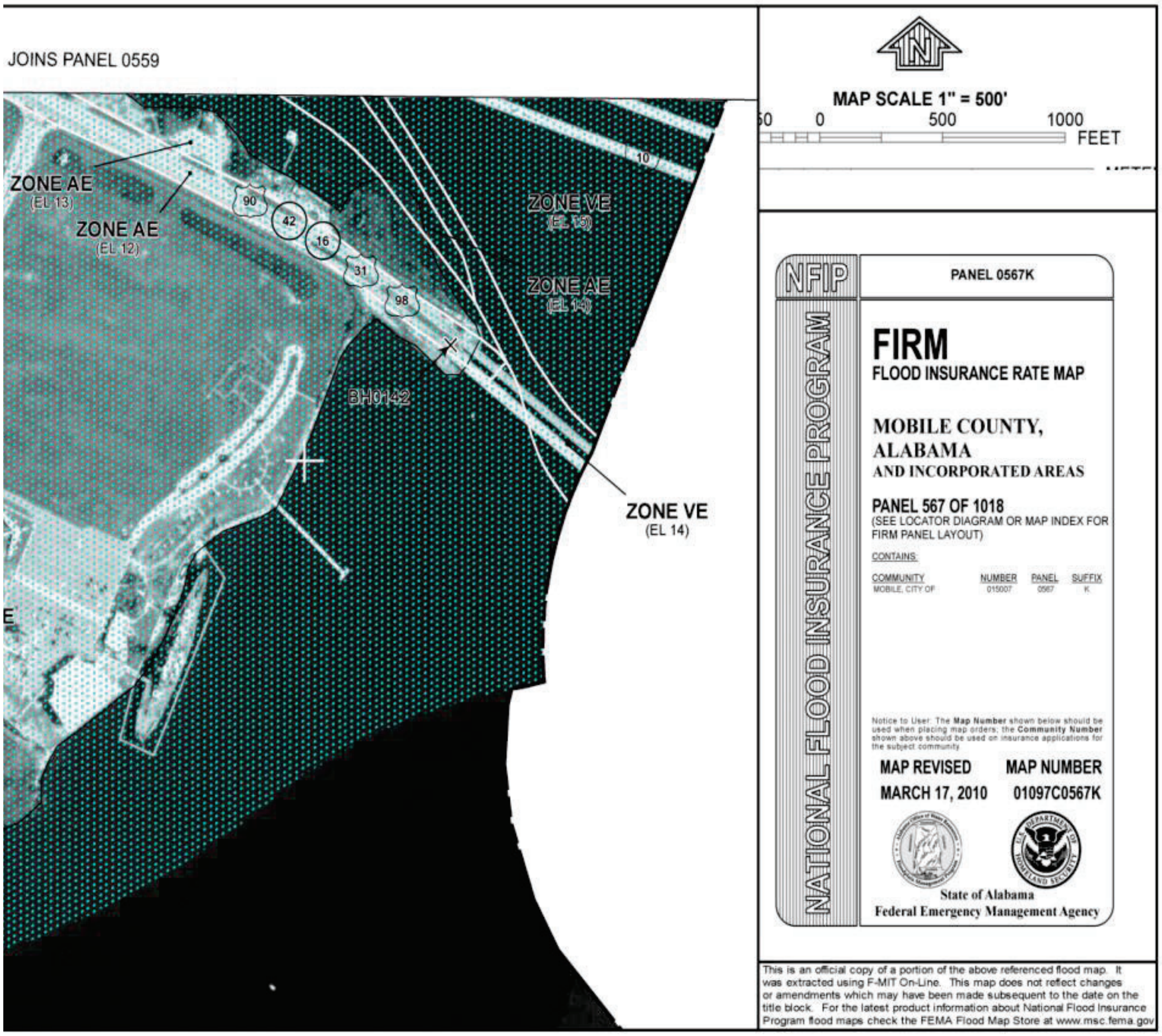
Figure 57: Flow Velocity Vectors and Evaluation Data Points at US 90/98 Tensaw-Spanish River Bridge



[204] Source of aerial image: Google Maps (as modified).
[205] Mudline is a reference to the ground elevation at the bottom of the channel at a given point.

Although the return periods of each of the surge scenarios now or in the future was not calculated, a comparison was provided to the current FEMA 100-year storm. As shown in Figure 58, the current FEMA 100-year storm overtops the entire abutment. The FEMA 100-year flood elevation is higher than the Hurricane Katrina Base Case Scenario, but less than the Hurricane Katrina Shifted Scenario as summarized in Table 27.

Figure 58: FEMA Flood Insurance Rate Map for the West Abutment of the US 90/98 Tensaw-Spanish River Bridge[206]



[206] FEMA, 2010b. Note: The elevations shown are in NAVD88.

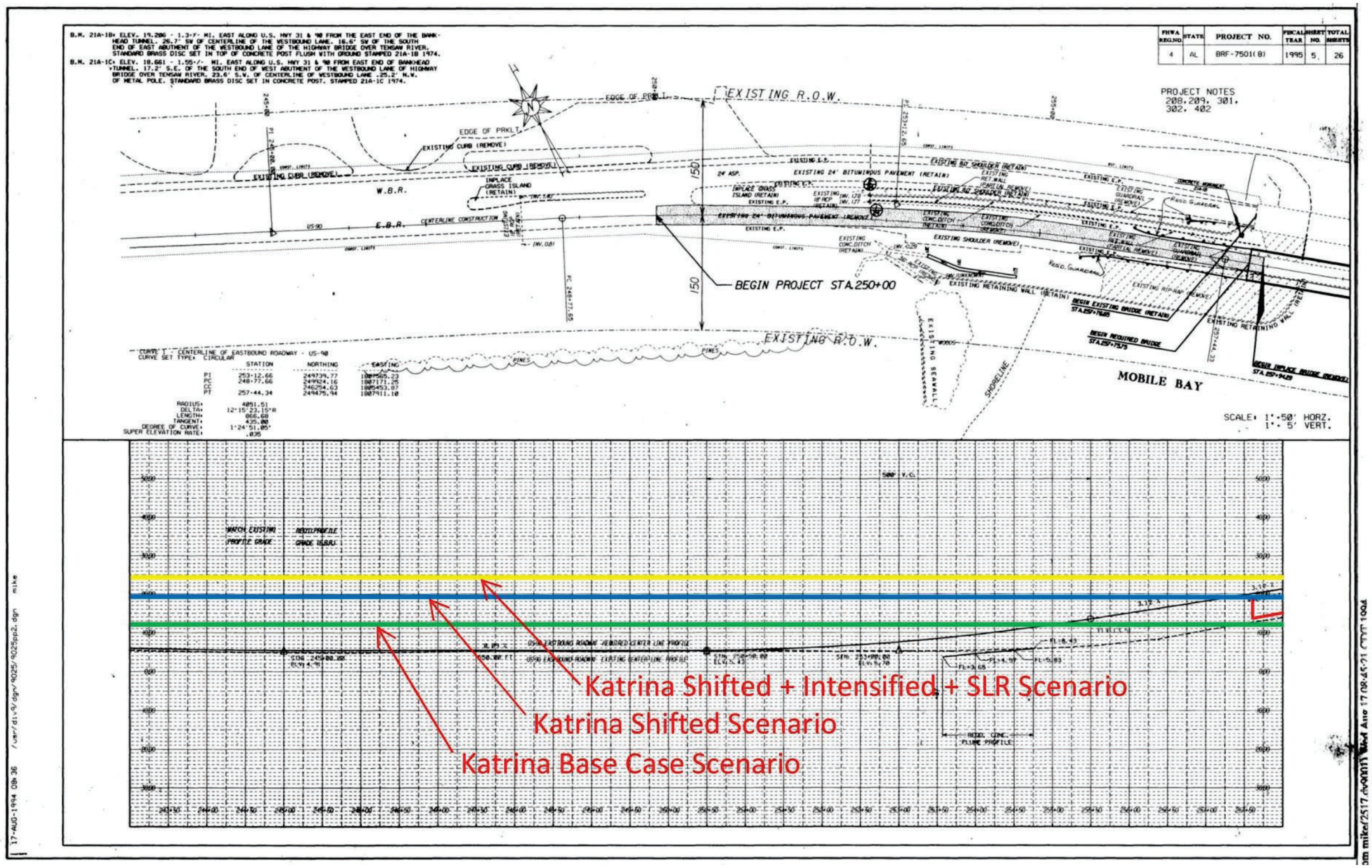
Table 27: Stillwater Elevations and Wave Heights at the Western Abutment of the US 90/98 Tensaw-Spanish River Bridge

Surge Scenario	Bridge Abutment Bottom of Girder / Roadway Top Elevation Feet (Meters) NAVD88	Stillwater[207] Elevation Feet (Meters) NAVD88	Wave Height Feet (Meters)
Hurricane Katrina Base Case Scenario	13.8/21.3 (4.2/6.5)	12.4 (3.8)	5.2 (1.6)
Hurricane Katrina Shifted Scenario		19.7 (6.0)	8.2 (2.5)
Hurricane Katrina Shifted + Intensified + Sea Level Rise (SLR) Scenario		24.6 (7.5)	4.1 (1.2)
FEMA Base Flood Elevation (100-year flood)[208]		14.0 (4.3)	

Figure 59 and Figure 60 show the surge stillwater elevations with respect to the approach to the western abutment and the bridge bottom chord elevation, respectively. The flooding profiles presented show that each storm surge condition overtops the timber bulkhead (elevation 5.5 feet [1.7 meters]), and will impact the abutment and the riprap along with the bulkhead and the willow mattress. Note that the stillwater elevations for two of the modeled storm surge scenarios and the FEMA base flood elevation overtop the western approach roadway. Additionally, the stillwater elevations of the Hurricane Katrina Shifted Scenario and the Hurricane Katrina Shifted + Intensified + SLR Scenario are higher than the lower chord of the bridge deck section in the area of the abutment. This overtopping condition will serve to lower the predicted abutment scour at the Tensaw-Spanish River Bridge but could result in damage to the roadway and loss of service during the surge and the immediate aftermath (due to clean-up). While issues related to the overtopping of the approach roadway and surge impacts on the bridge deck are not the primary focus of this study, they are larger issues of concern that are recommended to be investigated during the detailed evaluation of this or any bridge structure.

[207] Stillwater refers to the maximum elevation of a coastal storm surge without the addition of waves.
[208] FEMA, 2010b

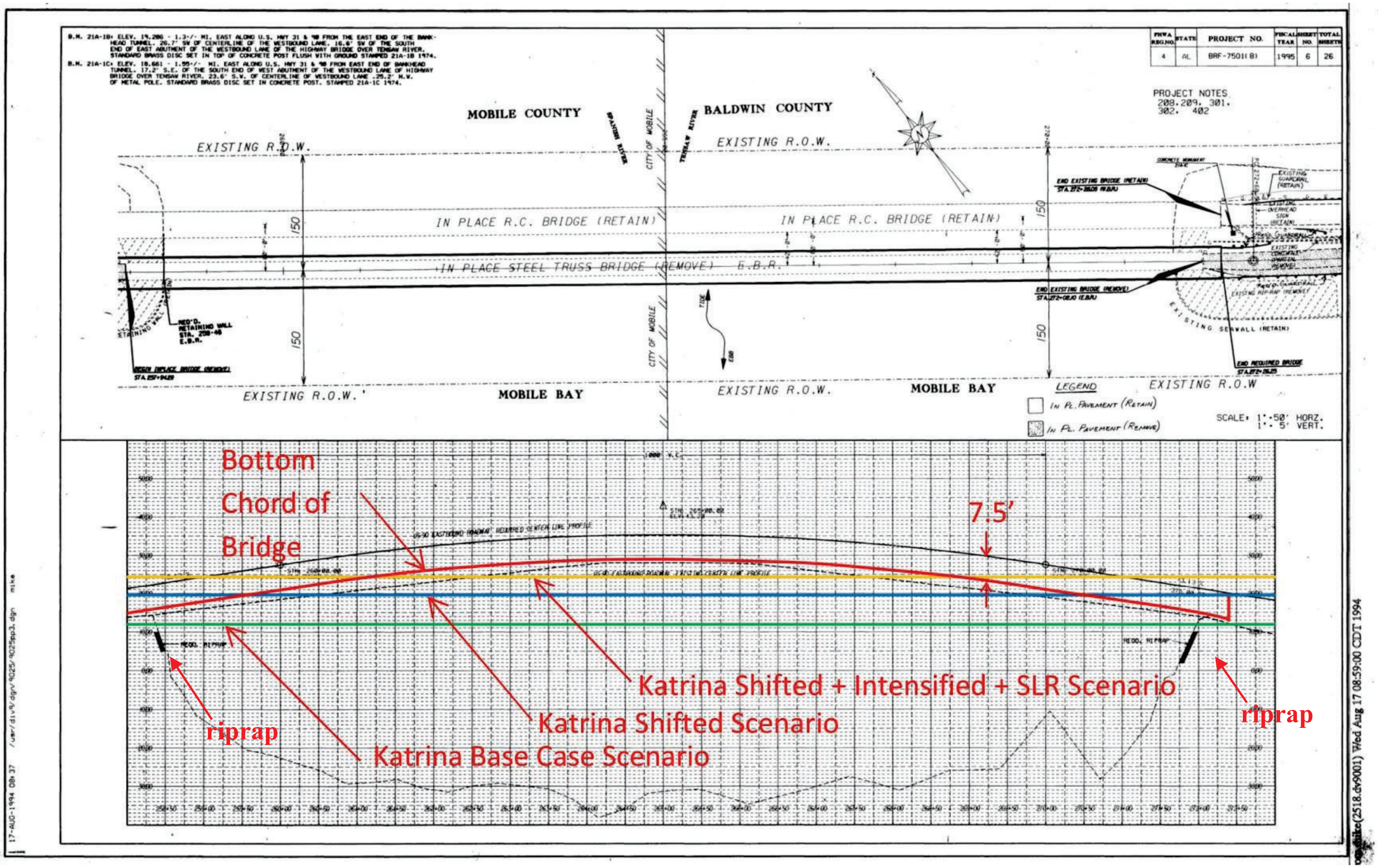
Figure 59: Plan and Profile of the Approach Roadway to the Western Abutment of the US 90/98 Tensaw-Spanish River Bridge with Water Levels[209]



[209] Source: ALDOT, 1994 (as modified)

FHWA002797

Figure 60: Plan and Profile of the US 90/98 Tensaw-Spanish River Bridge with Water Levels[210]

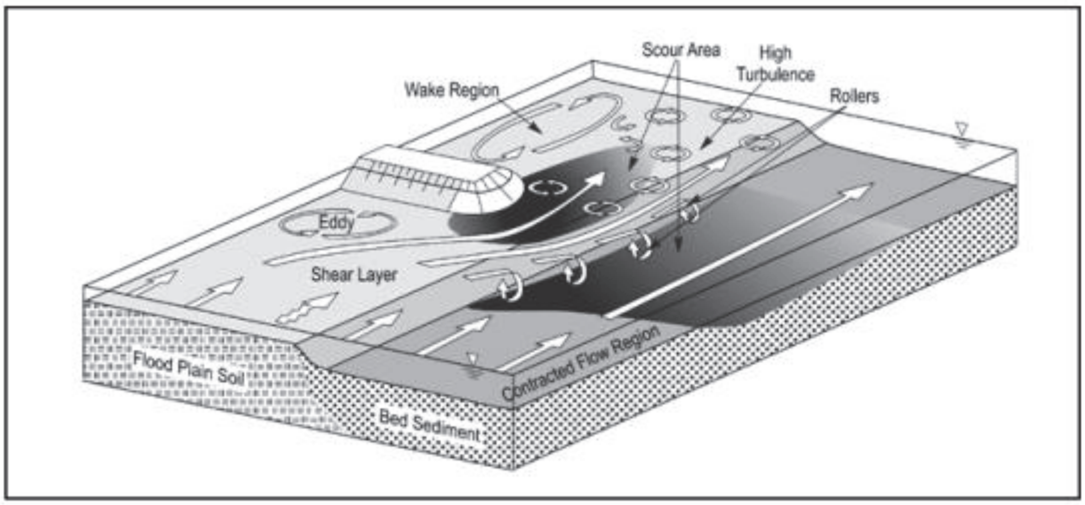


[210]Source: ALDOT, 1994 (as modified)

Step 5 – Assess Performance of the Existing Facility

Erosion of the soils at bridge abutments is generally caused by three hydraulic forces: contraction scour, horseshoe vortex formation, and wave vortices. Contraction scour occurs at abutments as the approaching flow is contracted from a wider flow area (in this case Mobile Bay) into the smaller bridge opening. As the flow is contracted, velocities are increased and the ability to erode soil can be greatly increased. Horseshoe and wake vortices are turbulent hydraulic formations that occur as flow impinges on a solid structure. Figure 61 shows the typical formation and shape of each of these vortices.

Figure 61: Schematic Representation of Abutment Scour[211]



Abutment scour is generally calculated as a combination of velocity, flow rate, flow depth, and geometric factors related to the abutment. In general, peak scour depths for any structural element normally occur when the flow velocity is highest. Under coastal storm surge conditions this peak velocity does not coincide with the peak water surface elevation. Due to the bi-directional nature of coastal surges (flood and ebb surge), the peak velocity occurs at two points, first during the flood surge and later during the ebb surge. The peak velocity for each of these conditions occurs when the rate of water surface change is at its greatest. In this case study, the peak flood and ebb surge velocities were compared at the approach locations (points E and D on Figure 56, respectively) and the velocities for the flood surge condition were found to be controlling. Thus, the abutment scour and protection computations were performed for the flood surge peak velocity.

A bridge abutment scour study usually requires a great deal of data, often collected on the latest foundation and material conditions at the abutments. Much of the required data was not available for this case study. Therefore, several assumptions were made concerning some basic inputs into

[211] NCHRP, 2011

the analysis. These assumptions were made specifically to be conservative in the estimation of impacts. Important assumptions for this analysis were:

- Soil borings or other geotechnical sampling and measurement data were not readily available at the abutment location. Given the location and setting of the bridge crossing, the soils were assumed to be medium sand with an average diameter of 0.01 inches (0.3 millimeters). For an actual study, the soils conditions should be ascertained from on-site boring information.
- A detailed bathymetric survey was not performed for this investigation, thus the channel bed data from the ADCIRC model was assumed to provide an accurate representation of the channel bed in front of the abutment. The ADCIRC model was built upon historic bathymetric and topographic data available from USGS and NOAA. While this data provides a reasonable basis for the current study, the accuracy of the data is expected to be limited by potential long-term changes to the channel bottom (sedimentation) or other influencing factors. Project specific bathymetric survey of the channel bottom would be recommended for a detailed study of the bridge abutment.
- Return period type storm events (e.g., the 100-year and 500-year storms) were not modeled as part of the coastal storm surge simulations for this project, thus the three chosen hurricane simulations were chosen as analogs for the design storms for the crossing.
- The abutments of the Tensaw-Spanish River Bridge have a complex protection scheme with the pile-supported abutment protected by willow mattresses, a bulkhead, and stone riprap. Following standard engineering practice, scour at the abutment was computed without the influence of the protections and the sufficiency of each protection was then investigated individually. Combining the results for each component's sufficiency – that is, for the abutment, willow mattresses, bulkhead and stone riprap – led to an overall conclusion on the stability of the abutment.

The three common abutment scour prediction equations presented in FHWA's *Evaluating Scour at Bridges; Fifth Edition* (HEC-18)[212] were assessed for their appropriateness to the case study site. The equations included:

- The Froehlich Abutment Scour Equation
- The HIRE Abutment Scour Equation
- The National Cooperative Highway Research Program (NCHRP) 24-20 Abutment Scour Approach[213]

The evaluation concluded that the HIRE equation development conditions did not meet the hydraulic conditions at the west abutment as the ratio of the flow depth to approach roadway length fell short of the recommended value of 25. The Froehlich equation was also investigated;

[212] Arneson et al., 2012
[213] NCHRP, 2010

however, as is often observed in practice, the equation produced overly conservative scour predictions. Thus, the NCHRP 24-20 approach was used for the detailed evaluation of the west abutment. The NCHRP approach was developed considering, "a range of abutment types, locations, flow conditions, and sediment transport conditions."[214] The approach considers contraction scour as a component of the total scour predictions, whereas the HIRE and Froehlich methods require a separate evaluation of contraction scour. The NCHRP method utilizes flow depth, unit discharges,[215] and a scour amplification factor[216] to compute total abutment scour. Chapter 8.6.3 of the HEC-18 publication includes a detailed discussion of the development and application of the NCHRP 24-20 approach. Table 28 presents the results of the NCHRP approach as applied to the west abutment of the Tensaw-Spanish River Bridge.

Table 28: Predicted Abutment Scour Depths and Elevations at the West Abutment of the US 90/98 Tensaw-Spanish River Bridge

Surge Scenario	Predicted Scour Depth Feet (Meters)	Predicted Scour Elevation Feet - NAVD[217] (Meters)	West Abutment Bottom Pile Elevations Feet-NAVD (Meters)
Hurricane Katrina Base Case Scenario	33.2 (10.1)	-43.2 (-13.2)	-17.7 (-5.4)
Hurricane Katrina Shifted Scenario	38.4 (11.7)	-48.4 (-14.8)	
Hurricane Katrina Shifted + Intensified + Sea Level Rise (SLR) Scenario	35.0 (10.7)	-45.0 (-13.7)	

As shown in Table 28, all three of the coastal storm surge scenarios result in scour depths that exceed the constructed depth of the abutment foundation. Thus, the analysis shows that the west abutment was not designed in consideration of full abutment scouring conditions, and in lieu of other protection factors, the abutment could be reasonably expected to fail. However, this design condition is not unique to this bridge design or unexpected. Given the widely held view that abutment scour equations produce overly conservative results, many state agencies have chosen to armor or otherwise protect abutments from scour rather than design the foundations for the full scour depth. In the case of the Tensaw-Spanish River Bridge, the previously noted riprap, willow mattress pad, and timber bulkhead have been utilized to protect the abutment from scouring. A comprehensive evaluation of the sufficiency of the abutment will be defined as the sum of the sufficiency of the protections, as the scour evaluation has shown that the abutment

[214] Arneson et al., 2012 (page 8.8)
[215] Unit discharges is defined as the average flow rate over a one foot (0.3 meter) unit width. Unit discharge has units of square feet per second as opposed to discharge which has units of cubic feet per second.
[216] Scour amplification factors are determined by charts specific to the NCHRP methods and are found as figures 8.9 through 8.12 in Arneson et al., 2012
[217] Predicted scour elevations estimated the bed elevation at the edge of channel being-10 feet (-3.1 meters)

itself will likely fail in their absence. In actual practice, the soils conditions should be accurately determined and, typically, a cost analysis performed to compare the costs of additional pile length to the cost of installing a number of scour protection measures. The following sections include evaluations of the scour and hydraulic sufficiency for each protection measure as related to the forces that constitute abutment scouring.

The upper most protection along the abutment is the rock riprap. The riprap runs from the top of the bulkhead to the top of the abutment. The design of the protecting riprap was evaluated using guidance set forth in the FHWA HEC-23 publication.[218] The size of riprap required to protect against scour in the abutment area is largely driven by the velocities of the flows modeled adjacent to the abutment (Point A in Figure 56). The Isbash relationship was utilized to compute the required size of riprap for protection of the abutment. The relationship has the following form:[219]

$$\frac{D_{50}}{y} = \frac{K}{(S_s - 1)}\left[\frac{V^2}{gy}\right]$$

Where;

y	Flow depth (feet)
V	Flow velocity (feet per second)
D_{50}	Median diameter of the rock riprap (feet)
K	Abutment shape coefficient (0.9, used for spill-through abutments)
g	Gravitational acceleration (32.2 feet per second squared [9.8 meters per second squared])
Ss	Specific gravity[220] of stone (2.7)

As discussed in Step 4, the classification of the existing riprap protecting the abutment was estimated to be Class 3 with a D_{50} of 15 inches (0.4 meters). Table 29 details the velocities, riprap size required, and the riprap size observed in place. The Isbash equation shows that the current riprap is sufficient to resist abutment scour. However, it should be noted that the riprap size from the Isbash equation does not consider wave impacts and the effects of general sea level rise on the embankment. These factors are analyzed in Section 4.4.3 and should be considered as part of the combined treatment of the abutment and approach embankment. The larger of the two rock sizes determined from the different approaches would govern and should be considered for use in armoring the abutment area. The results of the wave scour study are presented in Table 29 and show that the wave scour sized riprap with a 28 inch (71.1 centimeter) D_{50} (Class 5 riprap) would be recommended for placement along the entire abutment. While the computations have

[218] Legasse, Clopper, Pagan-Ortiz, Zevenbergen, Arneson, Schall, and Girard, 2009
[219] Legasse et al, 2009
[220] Specific gravity relates the density of one substance to that of another substance

shown that the current riprap sizing is sufficient to protect against storm surge induced currents, the riprap is not sufficiently sized to combat wave impact forces. As such, the riprap could represent a weak link in the scour protection for the abutment, in the event that the sea level rise and wave conditions documented in Section 4.4.3 occur. Readers are referred to Section 4.4.3 for a discussion of the sizing of the riprap for sea level rise conditions and associated adaptation options. The potential under-sizing of the riprap provides one area of potential weakness in the overall abutment protection scheme; however, since the system works together with multiple components, the bulkhead and willow mattress also factor into the overall vulnerability of the system.

Table 29: Required Riprap Size to Resist Abutment Scour at the Western Abutment of the US 90/98 Tensaw-Spanish River Bridge[221]

Storm Surge Scenario	Velocity at West Abutment (Point A) Feet/Sec (Meters/Sec)	D_{50} Computed Size Feet (Meters) – Abutment Scour	D_{50} Computed Size Feet (Meters) – Wave Scour	Estimated D50 Size of In-place Riprap Feet (Meters)
Hurricane Katrina Base Case Scenario	3.9 (1.2)	0.3 (0.09)	2.3 (0.7)	1.3 (0.4)
Hurricane Katrina Shifted Scenario	5.9 (1.8)	0.6 (0.2)		
Hurricane Katrina Shifted + Intensified + Sea Level Rise (SLR) Scenario	6.2 (1.9)	0.6 (0.2)		

The bulkhead protecting the southern side of the abutment is the next protection factor that was considered. As noted above, the bulkhead is a predominantly timber construction, but has been capped with concrete. As a solid structural element, the bulkhead is anticipated to perform following the same rules as the abutment. In this case, the bulkhead would either need to be designed to the full abutment scour depth, or would require stabilized protection as is the case for the abutment. While detailed pile tip information is not readily available for the bulkhead, the record drawings do show a length of 30 to 40 feet (9.1 to 12.2 meters) for the timber piles. The bulkhead has a top elevation of approximately 5.5 feet (1.7 meters) which would correlate to pile tip elevations between -25 and -35 feet (-7.6 to -10.7 meters), depths insufficient to protect the bulkhead against the peak scour conditions. An additional consideration for the viability of the timber bulkheads is the depth of the solid wood planking which retains the roadway fill behind the bulkhead. The wood planking is estimated to be present from the top of bulkhead to elevations -9.5-feet to –20.5-feet. While scour greater than these stated elevations may be

[221] Legasse et al, 2009

required to fail the timber piles which support the bulkhead, scouring to a depth below the wood planks will similarly result in a failure as fine fill materials used for the approach roadways will be readily eroded causing slumping, soil loss, and potential failure of the overlying roadway. However, as with the abutment, the ultimate stability of the bulkhead will be determined by also considering the protection afforded by the last component of the system, the willow mattress pad.

Willow mattress pads, also known as fascine[222] sinker pads, are a long-standing practice for the protection of bridges or other waterway structures. The structure is much more common in Europe, where it has a record of good performance. The willow mattress pad for the case study abutment was installed in 1963 prior to the construction of the southern (eastbound) bridge. Despite being constructed from natural woody materials, under anaerobic[223] and permanently submerged conditions these mats are very durable[224] and could still effectively function to prevent erosion. It was estimated that the permissible velocity[225] of the willow mattress pads was equal to or greater than 12 feet per second (3.7 meters per second),[226] the permissible velocity of a newly constructed brush layering revetment. The peak storm velocities for each of the analyzed conditions do not exceed the estimated permissible velocity for the willow mattress, thus the mattress is considered to be stable for all of the considered storm events.

Results of the evaluation of the individual protections show overall stability for the system. This conclusion is based upon a holistic review of the protection scheme which showed:

- The willow mattress pad is stable against the design condition flow velocities
- The bulkhead is protected along its base by the willow mattress pads and thus is also stable
- The riprap protection is appropriately sized for storm velocities
- The base of the riprap is protected by the bulkhead and the top of the riprap extends up to the concrete abutment, thus the riprap is also stable.

In consideration of the complex nature of the abutment protection scheme, each of the individual components was reviewed for stability under the various storm conditions. The review concluded that while the abutment itself is not designed to be stable under storm scour conditions, the protection components of riprap, bulkhead, and willow mattress have all been shown to be stable. Thus, the combined considerations for the abutment and the protection scheme shows that the system is stable and capable of performing for the current design conditions and each of the projected storm events. Ideally, the bridge abutment foundations would be designed for protection of the bridge and the approach roadway against the full depth scour event, providing a more sustainable protection than use of various scour countermeasures. However, the design and

[222] Fascine refers to the cylindrical bundle of sticks making up the pad.
[223] Anaerobic conditions refer to environments free of oxygen.
[224] Biedenharn, Elliott, and Watson, 1997
[225] Permissible velocity is the maximum velocity at which a given material meets stability criteria. Above this velocity a material may move or deteriorate.
[226] Fishenich, 2001

construction of bridges with the use of scour countermeasures over deep foundations is a common practice that is generally employed for bridge abutments.

That said, while the materials for protection of the abutment have been shown to be adequately sized, the materials used are subject to degradation over time. Proper maintenance and upkeep of the system is necessary to ensure the long-term success of the protection. As previously noted, review of the bridge underwater inspection records have shown that the condition of the bulkhead, willow mattresses and riprap armoring have not been as closely monitored as other aspects of the bridge. With the conclusion of this study and the observation that the stability of each of the three scour countermeasures is integral to the overall stability of the abutment, future inspections should include detailed inspections of each of these components.

Step 6 – Identify Adaptation Option(s)

The results of the abutment analysis concluded that the structure and provided protection measures were sufficient to meet current and projected storm conditions for all surge scenarios analyzed. Thus, adaptation for this particular system may not be necessary based upon the climate scenarios considered in this study. However, for other potential future climate scenarios that portend more extreme surges or for other abutments where adaptation measures might be needed, potential adaptive design options for controlling abutment scour include:

- Reconstruction of the protective bulkhead to a depth that is stable under projected scour conditions. Bulkhead would be constructed using a more sustainable material such as Fiber Reinforced Polymer or Vinyl sheeting to a deeper pile penetration. Riprap overlying the slopes above the bulkhead would be replaced with appropriately sized riprap coverage. Lastly, with bulkhead driven to the appropriate depth, the willow mattresses would not be necessary and protections further below the water could be removed from the bridge.
- Controlling the approach and departure flow to realign water passage though the waterway. This could be done by providing a stable and gradual transition to and from the bridge opening by using guidebanks, spur dikes, bendway weirs, or vanes.[227]
- Armoring of the bridge opening with riprap, concrete revetment,[228] or bulkhead / retaining walls
- Modifications to the bridge including widening, lengthening and / or shifting it
- Control of drainage from the embankment and roadway to avoid erosion starting in the abutment area

Step 7 – Assess Performance of the Adaptation Option(s)

No adaptive measures have been proposed for the study site. For abutment sites where adaptation options would be required, the performance of each adaptation option relative to each climate

[227] Guide banks, bendway weirs, spur dikes, and vanes are all rock riprap formations that are strategically placed to direct flows into the center of a bridge opening.
[228] Concrete revetments would include large or interconnected concrete blocks placed as embankment armoring.

scenario should be evaluated. This will provide important information for use in the economic analysis.

Step 8 – Conduct an Economic Analysis

An economic analysis is not required for this case study since no adaptation options were deemed necessary. For other abutment studies where adaptive alternatives have been proposed, see Section 4.4.1 for an example of how an economic analysis could be applied.

Step 9 – Evaluate Additional Decision-Making Considerations

The case study for abutment scour does not recommend any adaptive design measures for the Tensaw-Spanish River Bridge west abutment. However, for other abutment studies where adaptations are required, factors that will influence whether abutment protective measures are installed include:

- **Redundancy**: Abutment failures can take a long time to repair, resulting in road closure or reduced capacity. Not having redundancy in the network in case of failure should weigh on the decision of whether to pursue adaptation measures.
- **Constructability:** Retrofits to bridge foundations are complex and difficult construction projects, and could result in the temporary closure of a structure. Constructability and traffic studies to ensure that a proposed project is feasible could be a key consideration for any type of bridge adaptation project. Scour countermeasure work can present constructability issues due to limited clearance over many low lying bridges or due to limited or difficult access to the embankment slopes of shoreline.
- **Durability and maintenance**: The durability of scour countermeasures, especially in light of expected surge, is a key criterion in the design of such measures. In addition, the level of maintenance associated with the countermeasures should be considered.
- **Environmental issues**: Given their innate proximity to waterways and position along shorelines and streambanks, the use of scour countermeasures or construction activities could have negative impacts on the environment. In the evaluation of adaptations the impacts of both construction access and of changes in the shoreline / streambank composition (i.e., covering a sandy shoreline with large riprap armor stone or disturbing aquatic vegetation beds for placement of a scour countermeasure) should be carefully considered. Adaptation options should protect and minimize the impact on habitat and natural resources.
- **Aesthetics / recreational use** – This can be a key issue for public and stakeholder acceptance of adaptation countermeasures. In some locations, bridge crossings / abutments are located in highly visible areas, such as beaches or nature areas. In these locations, the use of a context sensitive treatment that does not limit the usage of the shoreline / riverbank or create an eyesore, should be considered. These considerations may include avoiding the use of armor stone due to its potential to both provide a hazard to pedestrians and its unsightly nature. Adaptations can consider the use of bioengineering treatments, subterranean countermeasures, or construction of stable foundations in lieu of countermeasures.

Step 10 – Select a Course of Action

The recommended course of action is to undertake no adaptations to prevent abutment scour at this time. This conclusion should be reevaluated if updated climate projections are developed that portend more severe surge conditions at the facility.

Step 11 – Plan and Conduct Ongoing Activities

Adaptation has not been recommended as a course of action for this study site, based on the combination of climate scenarios considered in this study. However, the materials used in the protection scheme for the abutment (riprap, bulkhead, and willow mattress pads) will all require regular maintenance inspections and periodic maintenance upkeep. Even with adequately sized riprap and willow mattress protection, these types of scour countermeasures are subject to degradation due to rocks shifting, settlement, or damage to the mattress or riprap from boat or debris impacts. The wearing of these revetments can occur due to several small storm events, but can be anticipated to accelerate during larger events. In keeping with Federal Highway Administration (FHWA) directives, the protections at the abutment should undergo periodic inspections (including inspections after significant storm events) that assess the condition of each protection element and recommend any needed repairs to the structures.

Conclusions

Based on the *General Process for Transportation Facility Adaptation Assessments*, this case study has demonstrated how a bridge abutment can be analyzed for various storm surge scenarios, including one factoring in sea level rise due to climate change. The analysis showed that the foundation design of the west abutment to the US 90/98 Tensaw-Spanish River Bridge is vulnerable to scour from all of the surge scenarios tested but that the existing protection measures in place today will provide adequate protection of the facility under each scenario. Thus, no adaptation option is recommended for the facility at this time to address the issue of abutment scour.

This case study demonstrated that the methodology for estimating abutment scour is very conservative, especially for typical coastal conditions. By standard practice, scour is usually protected against by adequately sized and installed riprap armoring. Abutment scour analysis procedures should be developed to allow for more accurate prediction and characterization of abutment scour. Updates to the equations would be appropriate and should include more open and detailed discussion within the design community related to both the development uncertainty inherent to the equations and the uncertainty related to scour prediction for any structure under changing climate conditions. With updates to prediction techniques, structural design guidelines should be updated to require the design of abutments to be stable without the need for outside protection schemes, such as riprap or a bulkhead.

This case study also included evaluation of underwater inspection records for the bridge which included the observation that current underwater inspection practices may not be fully considering the protection schemes at bridge abutments. Based on these observations, the practices performed during a given inspection should be revisited to ensure the long-term success of abutment scour countermeasures. Inspectors should be informed that even if the structural portion of an abutment is situated on “dry” ground, other components such as bulkhead, riprap, or other stability measures may play a key role in the overall scour resistance of the abutment and should likewise be monitored.

4.4.5 Bridge Segment Exposure to Storm Surge – The US 90/98 Ramp to I-10 Eastbound at Exit 30

Introduction

Bridges serve as important linkages between communities. With climate change, higher storm surges resulting from rising sea levels and potentially stronger coastal storms enhance the threat of devastating impacts to coastal bridges that can sever vital connections for long periods of time. One such vital connection is the bridge carrying I-10 (the Jubilee Parkway) across Mobile Bay (more commonly known as the "Bayway"); a 7.5 mile (12.1 kilometer) long structure connecting Mobile to the eastern shore of the Bay. This case study assesses projected storm surge impacts on a ramp connecting to that bridge: the elevated ramp leading from US 90/98 (the "Causeway") to I-10 eastbound at Exit 30.

The storm surge analysis for this bridge was conducted using the 11 step *General Process for Transportation Facility Adaptation Assessments*: this serves as the organizing framework for the remainder of the case study. The assessment determined that the portion of the ramp studied was currently highly vulnerable to damage from storm surges and will be even more so in the future. The recommended course of action is to de-commission all or a portion of the interchange served by the ramp after the next storm event that causes major damage. In the near-term, a detailed study exploring the implications of this action should be conducted.

Case Study Highlights

Purpose: To evaluate whether storm surge could cause a bridge to fail via any of three failure modes: (1) a wave uplifting and washing away the superstructure, (2) failure of the substructure due to the lateral forces of the wave, and (3) failure of the substructure due to excessive scour.

Approach: Failure Mode 1 was evaluated by using equations from AASHTO's *Guide Specifications for Bridges Vulnerable to Coastal Storms* to determine the forces on the superstructure under the selected storm surge scenarios, and comparing those forces to the force capacity of the bolts. Failure Modes 2 and 3 were evaluated by analyzing lateral and axial pile loadings with the procedures in AASHTO's *Guide Specifications for Bridges Vulnerable to Coastal Storms* and *LRFD Bridge Design Specifications.*

Findings: The bridge is likely not vulnerable to Failure Mode 1, but could be vulnerable to Failure Modes 2 and 3.

Viable Adaptation Options:

- Design bridge to breakaway to minimize overall damage
- Strengthen bolt connections
- Install open grid decks
- Design shallower girder sections
- Use open rail parapets
- Shorten the bridge, replacing lower segments with protected embankment

Other Conclusions: The worst case storm scenario does not necessarily translate to the worst effects on the facility. Also, retreat might be a viable adaptation option, but further study is needed to determine the costs of benefits of doing so.

Application of the General Process for Transportation Facility Adaptation Assessments

Step 1 – Describe the Site Context

The case study bridge is located on the east side of the Mobile metropolitan area at Exit 30 on I-10 (see Figure 62). The interchange at Exit 30 is uniquely situated in the middle of Mobile Bay where the bridge carrying the Bayway intersects with the Causeway. The case study bridge connects US 90/98 to I-10 eastbound and is located on the southwest side of the interchange (see Figure 63). Land uses served by Exit 30 include the USS Alabama Battleship Memorial Park and a number of local businesses. Exit 30 also acts as an important connection between the Causeway and the Bayway: in the event that an incident disrupts traffic on one of the roads, motorists can use Exit 30 to access an alternate route across the Bay.

Step 2 – Describe the Existing Facility

The case study bridge was built in 1974. The bridge is 27.8 feet (8.5 meters) wide[229] and approximately 1,205 feet (367.4 meters) long from its base at the Causeway to its intersection with the viaduct carrying I-10 eastbound. A total of 29 bents,[230] each one assigned a unique identifying number, support the bridge from Bent 1 at the beginning of ramp to Bent 29 at the merge with the I-10 viaduct.

[229] Width as measured to the outside faces of the parapets. The parapets are the outside walls on either side of a bridge that are designed to prevent vehicles from careening off the structure.
[230] Bents, also known as piers, are the vertical columns supporting each bridge span along with the horizontal member, called a cap, which holds them together.

Figure 62: Location of Exit 30 within the Mobile Metropolitan Area[231]

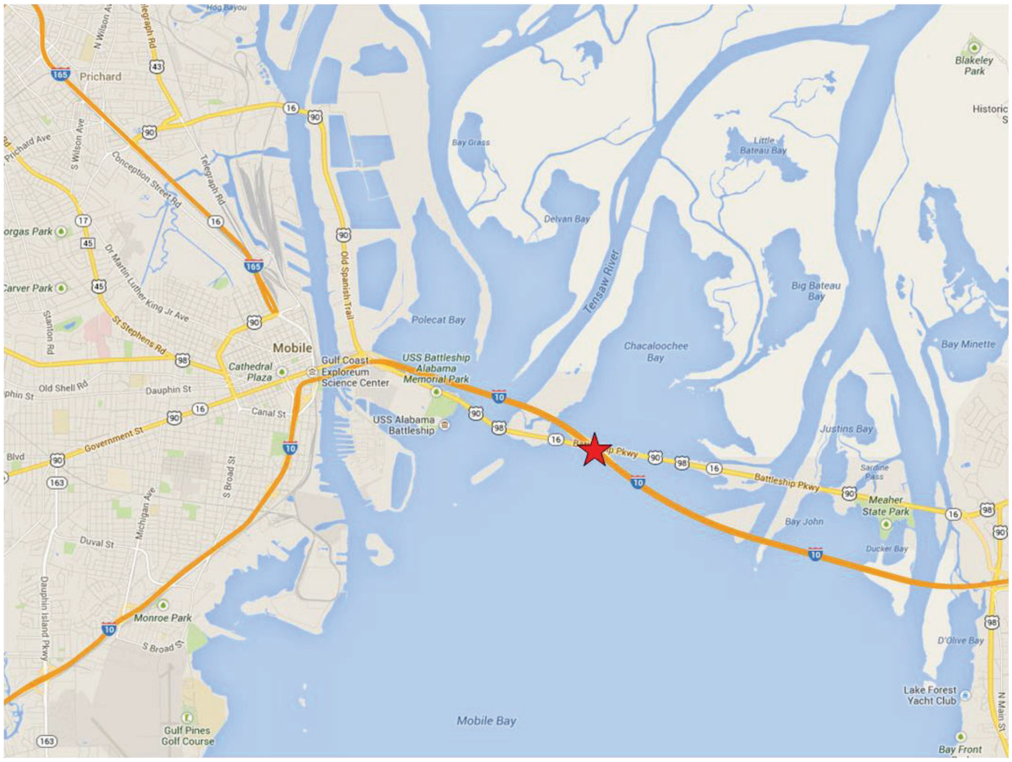


Figure 63: Location of the Ramp to I-10 Eastbound within the Exit 30 Interchange[232]

[231] Source of base map: Google Maps (as modified)
[232] Source of base map: Google Maps (as modified).

At the suggestion of ALDOT, the case study analysis focuses on the portion of the bridge between Bents 9 and 14 due to damages incurred on this segment from recent storm surge events associated with Hurricanes Katrina and Georges. This portion of the bridge is highlighted in the plan view of the structure shown in Figure 64 and the elevation shown in Figure 65.

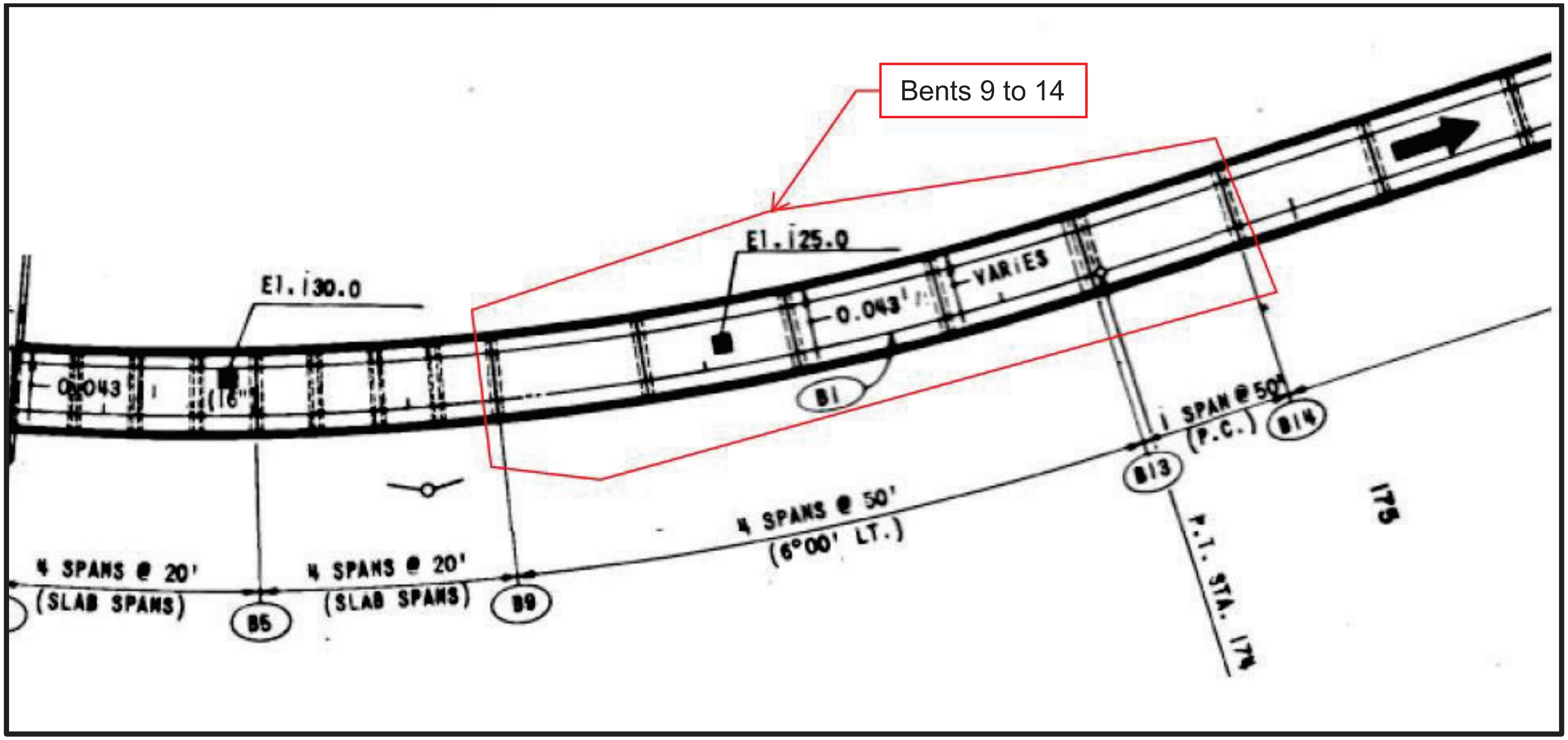
The five spans between Bents 9 and 14 are each 50 feet (15.2 meters) long making the portion of the ramp in this study 250 feet (76.2 meters) long. The superstructure[233] consists of a seven inch (178 millimeter) deck and four concrete beams spaced 7.3 feet (2.2 meters) apart (see Figure 66). The superstructure between Bents 1 and 9 is comprised of concrete slabs with no beams.

Under current sea levels, the (lower) Causeway end of the upward sloping bridge comes quite close to the Mean Higher High Water (MHHW)[234] elevation.[235] At the lowest bent, Bent 1, the clearance from the bottom of the slab to MHHW is approximately 1.2 feet (0.4 meter) and at the highest bent, Bent 29, the clearance from the bottom of the lowest beam to MHHW is 22.1 feet (6.7 meters). Within the segment being studied in this analysis, the lowest bent, Bent 9, has 2.3 feet (0.7 meter) clearance from MHHW whereas Bent 14, the highest bent, has 9.6 feet (2.9 meters) clearance from MHHW.

Most of the bents in the study segment consist of three 24 inch (60.1 centimeter) square concrete piles[236] topped with a concrete pile cap[237] (see Figure 67). The exception is Bent 13, which is a fixed anchor bent that does not allow the ends of the girders[238] to move, and contains six concrete piles (see Figure 68). The bents at the other sections of the ramp, Bents 1 to 8 (which support concrete slabs as the superstructure) and Bents 15 to 29 (which support concrete girders as the superstructure), are similar in construction to the section of ramp in this case study. The concrete beams are anchored to the top of the concrete pile caps with steel connection angles[239] and a series of bolts (see Figure 69). Bridge superstructures are typically connected to a bent (or pier) cap with a bearing and / or anchor bolts. The anchor bolts provides vertical uplift resistance and lateral force[240] resistance. In this case study bridge, the superstructure is connected to the bent cap with anchor bolts and horizontal through bolts (which penetrate through the entire width of the bottom of the concrete girders).

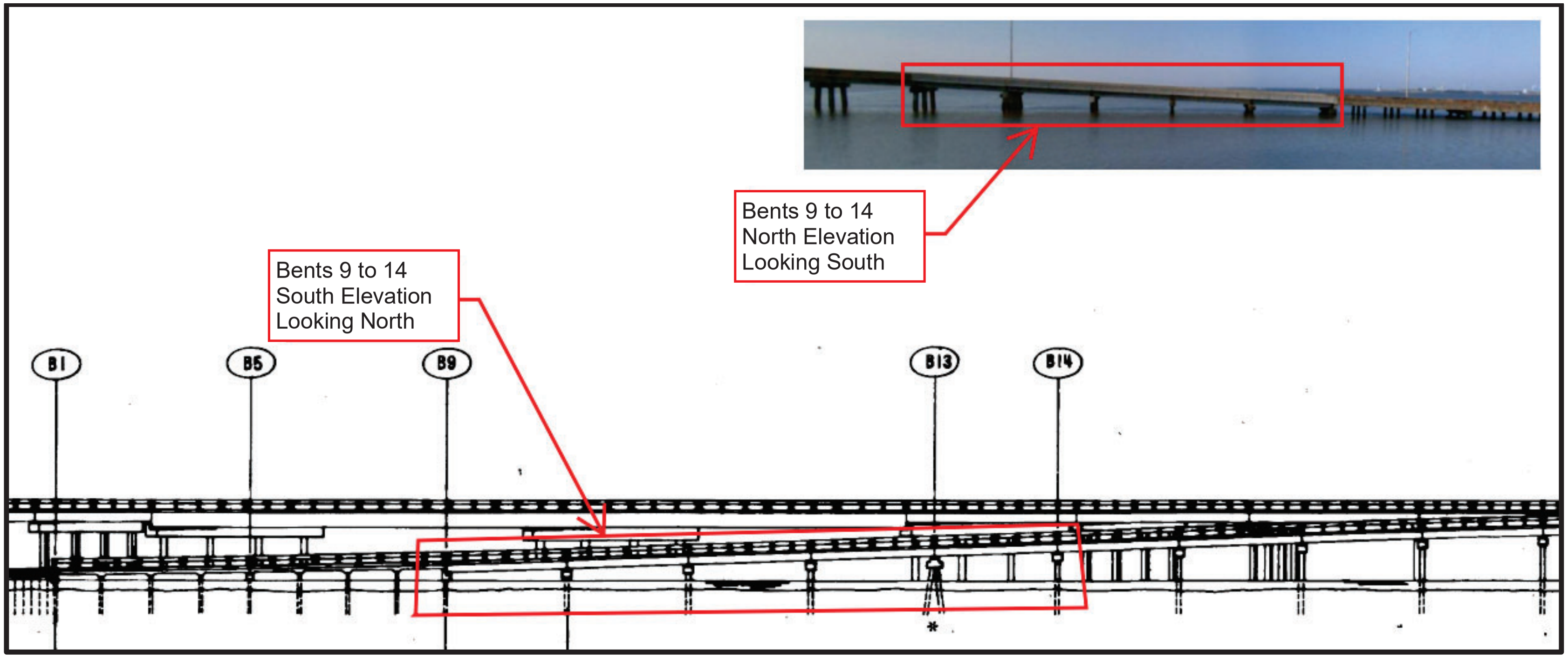
[233] The superstructure is the top part of the bridge and consists of the horizontal support girders, deck, and parapet walls preventing vehicles from falling off the structure.
[234] Mean higher high water is the average elevation of the highest daily high tide over the current National Tidal Datum Epoch. The tidal epoch is the specific 19-year period over which NOAA uses to obtain observations that are used to develop tidal statistics.
[235] All elevations within the text are with respect to the North American Vertical Datum of 1988 (NAVD88).
[236] Piles are the vertical support structures extending from the bridge deck to the seabed below.
[237] The pile cap is the horizontal member that ties together the vertical piles.
[238] Girders are the main horizontal supporting members of the bridge; there are four concrete girders for this case study bridge.
[239] Steel connection angles are used to connect the concrete girders to the concrete pile cap.
[240] Lateral forces are the horizontal component of a force affecting a structure.

Figure 64: Plan of the Bridge to I-10 Eastbound at Exit 30 Showing the Section of Analysis (Bents 9 to 14)[241]



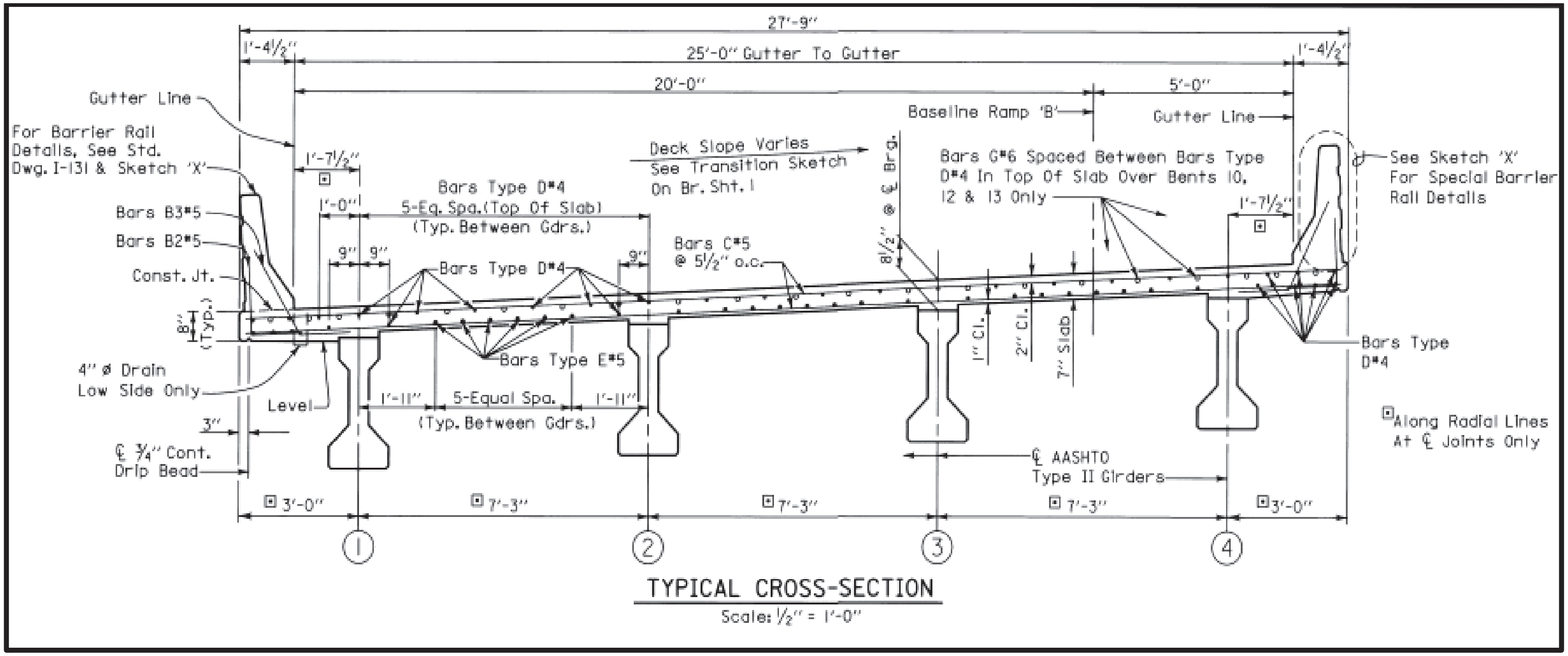
[241] Source: ALDOT, 1974 (as modified)

Figure 65: Elevation of the Bridge to I-10 Eastbound at Exit 30 Showing the Section of Analysis (Bents 9 to 14)[242]



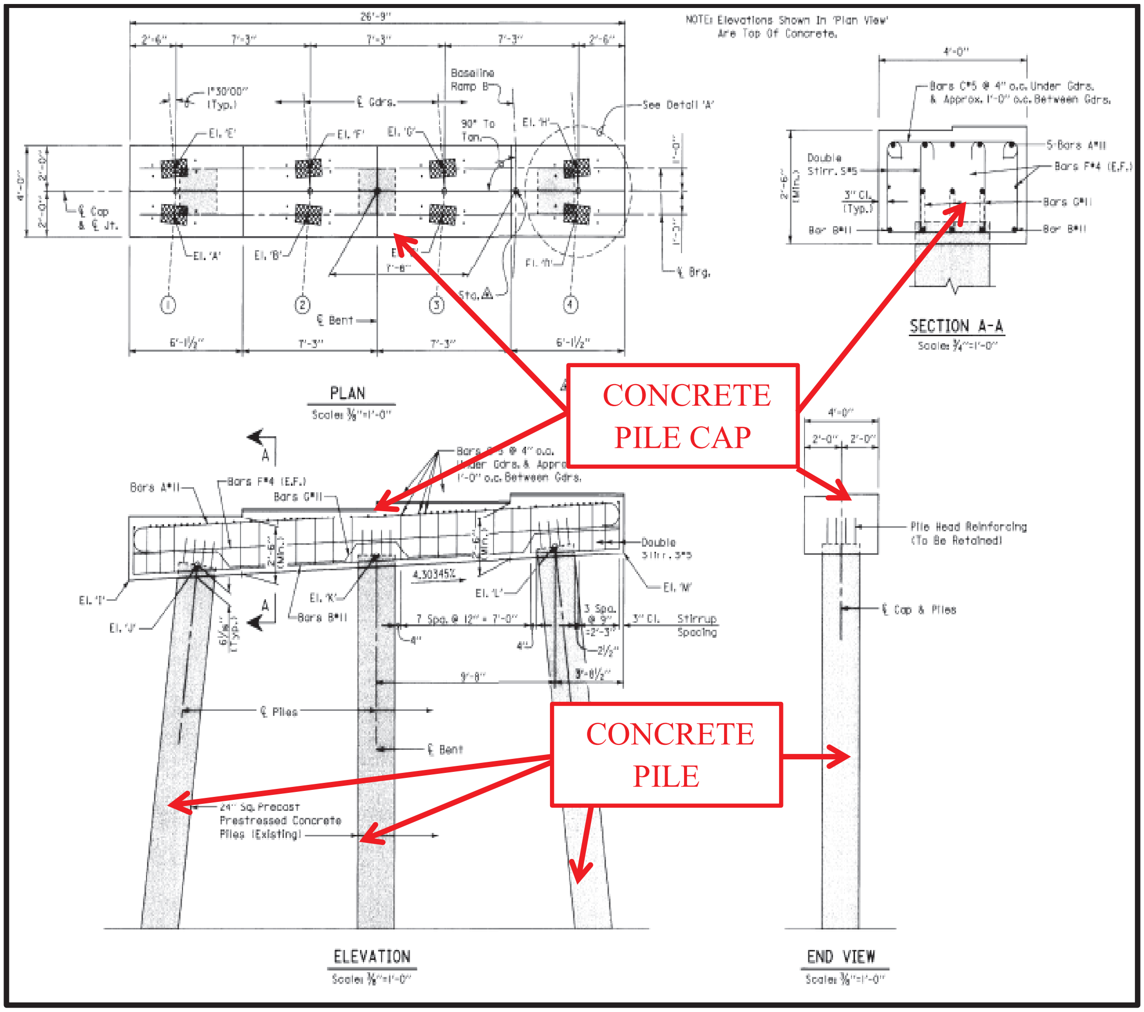
[242] Source: Elevation diagram from ALDOT, 1974 (as modified). Photo from Bing Maps (as modified).

Figure 66: Typical Section of the Superstructure between Bents 9 and 14 on the Bridge to I-10 Eastbound at Exit 30[243]



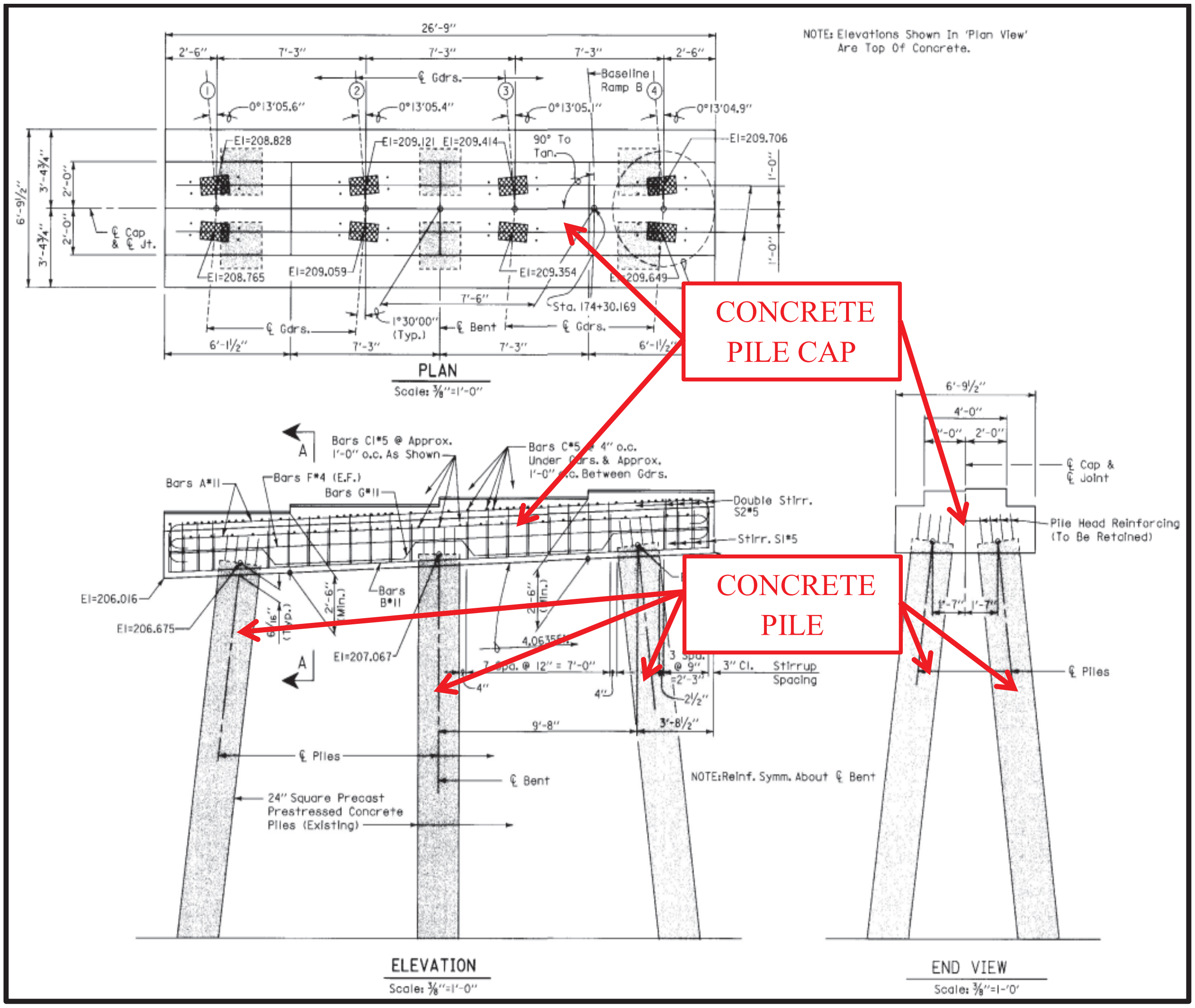
243 ALDOT, 2006

Figure 67: Typical Bent Details (Bents 10, 11, and 12) on the Bridge to I-10 Eastbound at Exit 30[244]



244 Source: ALDOT, 2006 (as modified)

Figure 68: Bent 13 Details on the Bridge to I-10 Eastbound at Exit 30[245]



245 Source: ALDOT, 2006 (as modified)